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Nitrogen use efficiency of cotton following corn in rotation and foliar fertilization of cotton using leaf blade analysis

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NITROGEN USE EFFICIENCY OF COTTON FOLLOWING CORN IN ROTATION AND FOLIAR FERTILIZATION OF COTTON USING LEAF BLADE ANALYSIS

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ABBREVIATIONS

Fertilizer Uptake Efficiency	FUE
Dry Matter	dm
Nitrogen Use Efficiency	NUE
Days After Planting	DAP
Foliar N as Needed	FAN

ABSTRACT

Research is needed to ensure proper cotton N fertilization in various production practices without the detrimental effects of excess fertilization on yield and the environment.

The objectives i) to evaluate the effect of residual N on the uptake efficiency of cotton-applied N when following corn in rotation, ii) evaluate the potential for using leaf blade analysis and preset N thresholds to trigger foliar applications of N to cotton grown on clay soils and iii) evaluate the effect of preplant N on early root and shoot growth and N assimilation of cotton grown on a clay soil.

Nitrogen rates of 0, 56 and 112 kg N ha^{-1} as double labeled 5 atom% ^{15}N $NH_4NO_3^-$ were applied to cotton grown on Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent) following previous corn N rates of 0, 168 and 280 kg N ha^{-1}. Total dry matter accumulation, total N assimilation and seedcotton yield on the upper third of the plant increased as corn- and cotton-applied N increased. Recovery of labeled N ranged from 40-53% in 1999 and 30-58% in 2000 and was highest following 0 or 168 kg N ha^{-1} previous corn-applied N in both years. More plant N assimilation was soil-derived in both years following 280 kg corn-applied N ha^{-1}. Application of 112 kg N ha^{-1} resulted in the most ^{15}N assimilated but uptake efficiency was the lowest. Seedcotton yields of cotton grown on Sharkey clay (very fine, montmorillonitic, non-acid, thermic, Vertic Haplaquepts) using 44 or 67 kg soil-applied N ha^{-1} along with foliar N as

needed averaged 622 kg ha^{-1} less than the recommended soil-applied rate of 134 kg N ha^{-1} although N use efficiency was 34% higher. The lower yield occurred because of fewer bolls on the second and third fruiting positions of upper sympodial branches. Preplant N rate increased dry matter partitioning to shoots with potentially larger N reserves. This provided ample vegetative growth, more branching and production of fruiting sites, and provided adequate assimilate to meet this increased demand. Increased cotton yield appeared to be the result of N accumulation and not greater root growth.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Cotton, like most crops, requires N for normal growth and development and farmers rely heavily on N fertilizers. Research involving N in cotton has been studied for many years (Wadleigh, 1944; Phillips et al., 1987; McConnell et al., 1993; Boquet et al., 1995; Boquet and Breitenbeck, 2000). Cotton N management is complicated by the indeterminate growth habit of cotton, often resulting in a fine line between deficient and excessive N application. Responses to fertilizer often vary from year to year and from location to location. It is because of this variation that research continues to explore new information regarding N management. Cotton has been the cash crop for many areas in the Midsouth, including Louisiana. In 1990, cotton in Louisiana accounted for $423 million in gross farm value (Funderburg and Burch, 1991). Recently, Midsouth farmers have replaced much of the land previously planted in cotton with corn. Although some growers have grown corn as a rotational tool, lack of profitability of cotton, relative ease of corn production and the Freedom to Farm Bill have been the major reasons for the large acreage shift. Depending upon grain yield, rainfall and corn-applied N rates, large amounts of residual N may be found in the soil in the year following corn production. If cotton is in a rotation with corn, questions may arise regarding cotton fertilization in the year following corn. Although cotton requires moderate amounts of N for optimum growth and profitability, overfertilization can cause problems such as rank (excess vegetative) growth, delayed maturity, increased insect problems and harvesting difficulties. If residual N is not available or adequate for crop growth, application of too little N may not meet crop requirements and results in poor yield. There is very little information about how efficiently cotton utilizes the residual N left from corn the previous year. Because corn-cotton rotations are widespread, information is needed to determine how cotton will utilize this residual N.

Proper N fertilization of cotton is required for optimum yields regardless of previous crop. It has been found that the fertilizer N requirement of clay soils is 30 to 40 percent greater than that for silt loam soils (Maples et al., 1992), however, N fertilization problems are not limited to clay soils. All soil types including sandy loams require proper N fertilizer management. One question that is constantly addressed is the efficiency of placement and application of N fertilizers during the growing season. Typically N is applied before or near planting and often supplemented later in the growing season by sidedress treatments or foliar applications. The question that remains is how much of this applied fertilizer N is lost and how much is utilized by the plant. Additional fertilizer N is often applied to compensate for anticipated losses due to denitrification, leaching and immobilization. If N loss is less than expected, this additional N can lead to over-fertilization, which could promote rank growth, delayed maturity and ultimately lost profits. In an effort to avoid guesswork, N is often monitored throughout the growing season to improve N management. Petiole nitrate tests have been utilized in some states to assess N status throughout the growing season but are often misleading due to variations in the crop at time of sampling. Leaf blade tests are considered to be less variable than the petiole nitrate tests because they are less affected by climate and seasonal changes (Sabbe and Zelinski, 1990). Proper diagnosis of crop nutritional status along with efficient application of N could increase N fertilizer efficiency in clay soils and eliminate some of the guesswork of N fertilization.

1.2 Objectives

The general objectives of this study were to determine the N use efficiency of cotton following corn and evaluate supplemental, foliar-and soil-applied N in response to critical N levels determined by a leaf-blade N test. More specifically the objectives were as follows:

I. Determine the efficiency of fertilizer N applied to cotton following corn in rotation using ^{15}N.
II. Determine the combined effect of residual and applied fertilizer N on reproductive and vegetative growth.
III. Determine if supplemental foliar N may be applied as needed to satisfy cotton N needs according to thresholds established with a leaf blade N test.
IV. Determine early season indices of growth for roots and shoots and N concentration and distribution for cotton grown on a clay soil under three N regimes.

1.3 Cotton

Cotton belongs to the genus *Gossypium*, which is found in the Malvaceae family. Of the 39 or so species in the *Gossypium* genus, only four produce lint. Two of these species, *G. hirsutum* L. and *G. barbadense* L., are grown commercially in the United States (Mauney , 1986). *G. hirsutum* or upland cotton is the primary species grown in the Midsouth (as well as worldwide). The cotton plant has one of the most complex growth and development patterns of any major field crop. It has an indeterminate growth habit and sympodial fruiting branches. Although cotton is a simple perennial by nature, it is cultivated as an annual in most areas.

The primary axis of the cotton plant remains vegetative throughout the life of the plant. Axillary branches differentiate at the base of each leaf on the plant and these branch axes are responsible for all vegetative limbs (monopodia) and reproductive fruiting branches (sympodia). Two branch buds typically arise at the base of each leaf. The more prominent of the two buds has been designated the first axillary and the slower developing bud, the second axillary. Early in plant development, first axillaries tend to elongate into vegetative limbs. However, as plants are induced to flower, the first axillary becomes the fruiting branch and the second axillary remains vegetative (Mauney, 1986; Mauney and Ball, 1959). Understanding the vegetative and reproductive growth habits of cotton are important concepts when evaluating N distribution within the plant at different growth stages.

1.4 Nitrogen

Plant dry matter is generally composed of approximately 2 and 40% N and carbon, respectively (Beevers and Hageman, 1980). Nitrogen is required through all phases of plant development because this essential element is a constituent of both structural (cell membranes) and nonstructural (amino acids, enzymes, protein, nucleic acids and chlorophyll) components of the plant. Without sufficient N, deficiency symptoms in cotton include stunting, chlorosis, and fewer and smaller bolls (Tisdale et al., 1993; Radin and Mauney, 1984).

1.4.1 Nitrogen Uptake and Assimilation

Most N used for plant vegetative growth is supplied from assimilated soil-N, except in the case of leguminous plants where N is fixed from atmospheric N_2. Nitrogen accumulates in plant tissues and some N may be remobilized several times during the growing season. During reproduction, N is remobilized from leaves by hydrolysis of proteins to amino acids and transported to developing bolls (Oosterhuis et al., 1983; Schrader, 1984). Nitrogen can also be released for re-assimilation during photorespiration as NH_3 released from glycine and also via turnover of proteins and nucleic acids.

Nitrogen is taken up by the root system where most reduction takes place and is then transported from roots to the shoots and leaves primarily as aspartate and glutamate (Schrader, 1984). Assimilation of NO_3 N includes three reductive and one non-reductive process in converting NO_3 N to NH_4^+ (Schrader and Thomas, 1981). The four enzymes involved are nitrate reductase, nitrite reductase, glutamine synthetase and glutamate synthetase. Nitrogen uptake during the growing season is generally low during the early part of the growing season with plants in the Midsouth assimilating approximately 0.25 kg ha^{-1} d^{-1} until the onset of squaring (Boquet and Breitenbeck, 2000). As the season progresses, assimilation of N increases until a maximum assimilation of 2.9-4.3 kg ha^{-1} d^{-1} occurs between 49 and 71 days after planting (DAP) (Boquet and Breitenbeck, 2000). In Alabama, Mullens and Burmeister (1990) found that the maximum daily N assimilation rate occurred slightly later in the growing season but maximum daily N assimilation values were similar to those found by Boquet and Breitenbeck (2000). Alternatively, Basset et al., 1970 found that the maximum daily assimilation rate was 1.5-2.0 kg ha^{-1} d^{-1} in California with Acala cultivars under irrigated conditions.

1.4.2 Nitrogen and Cotton Development

Cotton canopy development is strongly influenced by N uptake (Wullschleger and Oosterhuis, 1990c). During the vegetative stage of growth, rapid expansion of the leaves requires large amounts of N and both fruit production and retention are dependent on leaf development and photosynthetic integrity (Oosterhuis et al., 1983). Photosynthesis plays a major role in cotton production (Guinn et al., 1976; Wells et al., 1986; Wullschleger and Oosterhuis, 1990a) and studies show a strong relationship between leaf N concentration and single leaf photosynthesis (Wullschleger and Oosterhuis, 1990b; Bondada, 1994). The reason for this association is the large fraction of N associated with photosynthetic enzymes (Shiraiwa and Sinclair, 1993). Demand for assimilates increases as the growing season progresses and reproductive organs become the major sinks. This demand for assimilates is countered by declining leaf N and single leaf photosynthesis during this period (Oosterhuis and Wullschleger, 1992; Zhu and Oosterhuis, 1992). However, because rapid export of N from leaves to the developing bolls often coincides with a decline in leaf activity, yield could be decreased if boll demands exceed N reserves (Gardener and Tucker, 1967; Thompson et al., 1976; Oosterhuis et al., 1983; Rosolem and Mikkelsen, 1989; Leffler, 1976; Zhu and Oosterhuis, 1992). Although cotton seeds need large amounts of N at this time, too much available N may cause excessive vegetative growth and immature bolls which may result in harvesting difficulty and reduce fiber quality. However, not enough late-season N can lead to loss in economic yield (Parvin and Smith 1985; Waddle, 1984).

1.4.3 Cotton N Requirements

Hearn (1981) found that cotton requires about 90 kg N ha^{-1} for one bale of lint and about 140 kg N ha^{-1} for two bales of lint depending upon soil texture. However, uptake can be as much as 230 kg N ha^{-1} and N removal at harvest can be as much as half of total uptake (Hearn, 1981). Many studies have been conducted on the relationship between cotton dry matter and N accumulation. In California under irrigated conditions, Basset et al., (1970) found that cotton produced a total of 8900 kg ha^{-1} of dry matter and assimilated a total of 142 kg ha^{-1} of N using a N rate 134 kg N ha^{-1}. In Israel, also under irrigated conditions, using Acala cultivars, Halevy (1976) found that plants receiving 100 kg N ha^{-1} produced a total of 12,000-13,480 kg ha^{-1} of dry matter. These plots assimilated a total of 235 kg N ha^{-1} of which 42-49% was removed at harvest. In Louisiana, Boquet and Breitenbeck (2000) found that cotton produced a total of 5275, 10103, and 8196 kg ha^{-1} of above ground dry matter under dryland conditions using N rates 0, 84 and 168 kg N ha^{-1}, respectively. They also found that plots receiving 0, 84 and 168 kg N ha^{-1} assimilated 98, 209, 242 kg N ha^{-1}, respectively. Their study also showed that plots receiving an excessive N rate (168 kg ha^{-1}) produced a higher amount of dry matter in shed material (i.e. leaves and small bolls) which was believed to be due to excessively large plants that increased self-shading.

1.4.4 Nitrogen Management

Cotton is a crop that generally needs fertilizer N but the optimum rate is highly variable and dependent on many factors. Using the optimum N rate for cotton creates a correct balance between vegetative growth and fruit set, which contributes to earlier boll set, minimal loss from boll rot, minimal number of insecticide applications, minimal need for growth regulators, decreased defoliation cost, earlier maturity and harvest, and optimum yield. Excess N fertility, on the other hand, causes excess vegetative plant growth, which contributes to opposite effects on the above-mentioned parameters as well as decreased micronaire and increased immature fiber content. The cost of excess N fertility can clearly be quite high as a result of the increased inputs required to manage over-fertilized cotton. Because of the fine line that exists between N excess and deficiency, many N management strategies have been evaluated to improve efficiency. The application of N is often subjective and based on potential yield, soil type and field history. Generally, N is applied prior to or at planting in single applications. In some cases split applications are used where a portion (1/3-1/2) of the N is applied at planting and the remainder applied sometime before first bloom (Maples and Frizzel, 1985; McConnell et al., 1993). Boquet et al. (1991) found no significant yield advantages in Louisiana to applying N in split applications. As with application timing, N recommendations vary from state to state. Louisiana currently recommends 67-100 kg N ha^{-1} on coarse textured soils and 90-134 kg N ha^{-1} on finer textured soils (Barnett, 2000). The University of Arkansas recommendations are primarily based on soil tests and plant analysis although other N recommendation criteria including yield potential, soil organic matter, soil texture, climate and previous cropping history help make management decisions (Maples et al., 1992). Mississippi recommendations are based on soil texture and “realistic yield potential”. Cation exchange capacity (CEC) is used to determine soil texture and soils with a CEC <14 have a recommended range of 67-90 kg ha^{-1} while 112 kg ha^{-1} is recommended for soils with a CEC of >14 (McCarty, 2000). Regardless of what technique is used, N fertilization of cotton is subjective and varies regionally as well as from farm to farm.

Tradition and experience have been the primary factors for determining the specific N rate for a particular cotton field. Optimum N rates have been reported as low as 35 kg ha^{-1} and as high as 135 kg ha^{-1} (Touchton et al., 1981; Maples and Frizzel, 1985; Howard and Hoskinson, 1986; Lutrick et al., 1986; Phillips et al.; 1987). Hardy and Garrett (1965) found that cotton yield increased with fertilization up to 100 kg ha^{-1} on a Sharkey silty clay. Maples and Keogh (1977) found that cotton yield leveled off in sandy loam soils at applications of 67 to 100 kg ha^{-1} and decreased with 134 kg ha^{-1}. On Sharkey clay soil they found that 100-134 kg ha^{-1} was needed for maximum yield (Maples and Keogh, 1977). Australian researchers found that maximum cotton yields on clay soils were achieved with 140 to 246 kg ha^{-1} (Constable and Rochester, 1988) suggesting that higher N rates are needed on finer textured soils. However, on coarse textured soils, increasing N rate may induce excessive vegetative (rank) growth. This rank growth, depending upon harvest conditions, may result in reduced yields (Maples and Keogh, 1977). Rank growth is typically not a problem on clay soils and increased N rates are often needed to stimulate vegetative growth (Constable and Rochester, 1988). Considering the narrow range that exists between N deficiency and excess, and the possibility of N loss by leaching or denitrification, split applications are often used (McConnell et al., 1993) but there is no evidence in Louisiana research that multiple N applications (including foliar) are more beneficial to yield than a single early-season application (Boquet et al., 1991). However, yield increases may not have been realized from these additional foliar applications due to sufficient N levels before treatment. Because cotton is grown over a wide range of soils, climates and cropping conditions, the N requirement and efficiency can differ from location to location and year to year (Ebelhar, 1990).

1.4.5 Nitrogen Tests

A combination of soil and plant tissue tests is often used to monitor cotton N status and there are several methods available. Soil nitrate tests have been used for years and have been shown to be effective for predicting cotton N requirements in the Western United States (Gardener and Tucker, 1967). These same tests are often less effective in more humid areas such as the Midsouth and Southeast possibly because NO_3^- does not accumulate in the soil profile after mineralization and is easily lost during rainfall events (Lutrick et al., 1986, Breitenbeck, 1990). Another test is the petiole nitrate test and is the most popular method used to monitor in-season plant N status. The test estimates flow of nitrate from the root to the leaf in the transpiration stream. Petiole nitrate analysis has proved to be effective in predicting N requirement in Arkansas, Georgia and Florida (Lutrick et al., 1986; Maples et al., 1990), as well as Oklahoma (Baker et al., 1972), and Texas (Sunderman et al., 1979). In Alabama (Touchton et al., 1981), Mississippi (Jenkins et al., 1982) and Tennessee (Howard and Hoskinson, 1986) the test has proven unsuccessful or inconsistent. Because petiole nitrate levels often vary with cultivar, growth stage, soil type, weather and insect damage, the test is difficult to interpret (Keisling et al., 1995; Heitholt, 1994; Sabbe and Zelinski, 1990; Maples et al., 1990; Oosterhuis and Morris 1979, Baker et al., 1972; Gardener and Tucker, 1967; Longnecker et al., 1964 and MacKenzie et al., 1963). The possibility exists that the petiole technique is not reliable after the third week of flowering (Keisling et al., 1995). A number of factors may contribute to this including soil N status, environmental stresses, water availability, and sink strength of the developing boll load, which is the most difficult to determine.

Another test that is often used to determine in-season N status is the leaf blade N test. Leaf blade tests are considered to be less variable than the petiole nitrate tests but also have limitations. Like the petiole nitrate test, significant variations may occur with different cultivars, growth stage, soil type, weather and insect damage (Bell et al. 1997, 1998). However, this test is believed to be a direct measure of the plant's N status and provides an estimate of cumulative N uptake prior to sampling and the amount of reserve N (Sabbe and MacKenzie, 1973; Sabbe and Zelinski, 1990; Bell et al., 1997, 1998). Leaf blades are thought to be less affected by climate and seasonal changes because most N has been reduced and is incorporated into plant proteins (Sabbe and Zelinski, 1990). Although variations also occur with this method, results indicate that more accurate predictions of cotton nutritional status may be made. Previous critical values for cotton at early bloom were 30 g N kg^{-1} dry matter (dm) (Mitchell and Baker, 1997), 35 g N kg^{-1} dm (Jones et al., 1991), and 36 g N kg^{-1} dm (Bergman, 1992). Values for mid bloom range from 30-40 g N kg^{-1} dm (Sabbe et al., 1972; Bergman, 1992; Boquet et al., 1995; Mitchell and Baker, 1997). Bell et al. (1997, 1998) have recently described Midsouth critical values for cotton leaf blades at different growth stages; 46 g N kg^{-1} dm at pin-head square, 40 g N kg^{-1} dm at early bloom, 38 g N kg^{-1} dm at mid-bloom and 33 g N kg^{-1} dm at cutout. values at early and midbloom were considered most reliable.

1.4.6 Foliar N Application

Previous research has suggested pre-plant and sidedress N applications may not meet crop demands (Maples and Baker, 1993). Nitrogen absorption from the soil is also often limited due to drought, soil compaction and general reduced root efficiency. Many new cultivars partition more of their photosynthate to fruit and less to roots and vegetative dry matter (Wells and Meredeth, 1984 a,b). The smaller root volumes result in decreased potential for soil applied N uptake. Moreover, when cotton plants begin fruiting, the photosynthate produced in the leaves is preferentially transported to the fruit and root activity declines (Gray and Akin, 1984). The root is still functioning but activity is often decreased and N uptake from roots may not be adequate. Since much of the photosynthate for a boll is received from the subtending leaf and bracts (Benedict et al., 1973;

Zhu, 1989; Zhu and Oosterhuis, 1992, Bondada et al., 1996; Bondada et al., 1997), any reduction in available N or carbohydrates may result in fruit abscission (Patterson et al., 1978). If or when N decline occurs, foliar applications of N could offer an alternate method of getting the N into the plant. Foliar fertilization has increased yields by allowing increased production of assimilates for bolls (Mathur et al., 1968; Oosterhuis et al., 1989; Bondada, 1994). Many studies have been conducted over the years evaluating the use of foliar fertilizers. Halevy and Markovitz (1988) reported availability of soil applied nutrients significantly alters the effectiveness of foliar applied treatments. They found that yield responses to foliar applications of N generally occurred when soil fertility was low. In some cases, however, yields were increased with foliar N application when soil N levels were considered adequate. Alternatively, Bednarz et al. (1998) did not find yield increases with foliar N application when soil N was adequate. Smith et al. (1987) found that foliar N application at peak bloom increased yields but Bednarz et al. (1998) found no yield increase. Decreased uptake due to leaf age and the increased surface wax content (Bondada et al. 1997) could explain variable yield response to foliar N applications. Surface features such as epicuticular wax act as a barrier to foliar applied substances (Kannan, 1986; Oosterhuis and Wullschelger, 1992; Bondada et al., 1997). Leaf age may also affect foliar N absorption (Cook and Boynton, 1952; Marshner, 1995). Bondada et al. (1997) found that 80% of foliar applied ^{15}N was absorbed by 20 d old leaves and as leaves aged to 60 d absorption decreased to 38%. As leaves become older, physiological activity decreases and senescence begins.

Older leaves, particularly those that are drought stressed, may not only have decreased photosynthetic activity but also thicker wax layers which further decrease epidermal uptake. Since older, subtending leaves generally accompany most bolls (Constable and Rawson, 1980), insufficient leaf N may reduce boll growth and decrease yield potential (Wullschleger and Oosterhuis, 1990a).

The most common form of N foliar-applied is urea ($(NH_2)_2CO_2$) (46% N) which is rapidly taken up through the leaf epidermis after application. The epidermal cell wall is covered by a cuticular layer and urea must first diffuse across the cuticle and cell wall (Harper, 1984) before being absorbed by the surface of the plasma membrane. Movement across this membrane appears to require metabolic energy (Franke, 1967). Generally, 60-70% is absorbed within 48 hours of application with the majority being translocated to the closest subtended boll (Zhu, 1989 and Bonadada et al., 1997). Bondada et al. (1997) found that 80% of foliar applied ^{15}N was absorbed within one week after application.

Urea applied at recommended rates has the potential to result in leaf injury depending on the conditions present at application (Clapp and Parham, 1991). The level of urease activity in the leaf may also affect leaf injury often associated with increased rates of urea. Higher urease activity within the leaf may cause rapid accumulation of NH_3 which is conducive to foliar injury (Harper, 1984). Although many questions remain about coupling the use of leaf blade N or petiole nitrate tests with foliar applications of N for cotton fertility management, the concept remains promising and more research is needed.

1.5 Cotton and Corn Rotation

Cotton has been grown in the Mississippi River delta region of Louisiana for many years. Recently, much of the land previously planted solely in cotton in the Midsouth has been shifted to corn in rotation with cotton. Rotation of cotton and corn typically increases cotton yields compared to those monocropped to cotton (Boquet and Hutchinson, 1993: Ebelhar and Welch, 1989). Reasons for crop rotation include weed control, disease and nematode control, reduced soil degradation and improved soil tilth, insect concerns and better profits (Hearn 1986). The basis for N recommendations for corn production are not unlike those for cotton and are often based on climate, soil classification, and yield goals (Voss, 1982; Liang et al., 1991). High fertilizer rates in conjunction with favorable climatic conditions can increase grain yields considerably. However, under unfavorable conditions, high fertilizer inputs may not only result in reduced profits but also result in environmental contamination (Liang and MacKenzie, 1994). Good corn yields can be made in the Midsouth if favorable conditions exist. Dry-land corn yields can range from 4480-11200 kg ha^{-1} depending on annual rainfall. In order to meet these yield potentials, Louisiana currently recommends 156-280 kg N ha^{-1} for corn yields of 8400 kg ha^{-1} or more. The upper range of fertilization is for soils with a higher clay content and those soils that are irrigated (Mascagni and Burns et al., 2000). Although corn demands large amounts of N fertilizer, the plant does not necessarily utilize all applied N.

Because overfertilization does not adversely affect corn yield, producers often apply excessive rates of N to non-irrigated corn in anticipation of adequate rainfall. During dry years, large amounts of fertilizer N may remain in the soil after harvest. Corn N uptake may equal nearly 300 kg N ha^{-1} during the season but N removal at harvest is generally only about 1.3% of total amount of grain removed (Potash and Phosphate Institute, Atlanta, GA). In the higher organic matter soils of the Midwest, considerable amounts of fertilizer N have been found in the soil organic N fraction. Kitur et al (1984) found that 28-42% of the fertilizer N applied to corn remained in the soil depending on N rate and tillage practices. Sanchez and Blackmer (1988) found 19-23% of the labeled N applied as anhydrous ammonia to continuous corn was still in the soil. Timmons and Cruse (1990) found 16-27% of N was still in the soil after continuous corn production. Bigeriego et al. (1979) found that from 4 to 40% of labeled N in ammonium sulfate was still in the soil after irrigated corn harvest. Two years after application of tagged ammonium sulfate, Olson (1980) found 40 and 46 % of labeled N was still in the soil after 50 and 150 kg N ha^{-1} rates, respectively. Although factors such as grain yield, tillage practices, rainfall, N placement and N rate play a large roll in the amount of residual N found after harvest, substantial amounts may remain.

Although rotations generally increase cotton yield and improve soil tilth, the potentially large amounts of residual N could be detrimental to cotton development. Cotton responds negatively to excessive N and large amounts of residual N may be available after corn harvest. Information is needed on how cotton will utilize the potentially large amounts of residual N following corn in relation to the cotton fertilizer N rates.

1.6 Use Efficiency and ^{15}N Labeling

In addition to N fertilizer, N for crop production is also obtained from mineralization of soil organic N, residual fertilizer N and biologically fixed N. Because all these sources of N are available for crop nutrition, it is important to know the efficiency of applied N in this respect. Researchers employ several methods of determining fertilizer use efficiency. Fertilizer use efficiency (FUE) is described as “the percentage recovery of fertilizer N by the crop” (Parr, 1973). The two methods most commonly used to determine FUE are the indirect or difference method and the direct or isotopic method. The difference method is often used in field experiments to estimate the fertilizer N recovery of many crops. With this method the total N uptake by plants from control plots is subtracted from the total N uptake by the N–fertilized plots and divided by the amount of N added to the fertilized plots (Schindler and Knighton, 1999). Boquet and Breitenbeck (2000) used the difference method to determine deficient, sufficient and excess N effects on the seasonal uptake and partitioning of N and dry matter of cotton. They found that approximately 240 kg N ha^{-1} was assimilated by plants receiving an excessive N rate of 168 kg ha^{-1}. This led to an apparent fertilizer efficiency of over 100%. They attributed this to a more pervasive root system and a greater demand for subsurface moisture (Boquet and Breitenbeck, 2000). Many researchers feel that this leads to a gross misinterpretation of fertilizer N recovery (Westerman and Kurtz, 1974; Moraghan et al., 1984; Torbert et al., 1992). The assumptions that often lead to this misinterpretation are that the mineralization, immobilization, and other soil transformations are the same for both the control and N-fertilized plots. Other factors such as microbial activity and root growth are assumed unaffected by N fertilization, which may also be erroneous (Schindler and Knighton, 1999). In order to circumvent these problems researchers use isotopic tracer techniques. By using tracer N, researchers are able to determine with some certainty the differences between fertilizer N and soil N. This enables them to directly measure the fertilizer N recovery. Most studies using this method use fertilizer enriched with ^{15}N. Atom percentages of 2-99% are often used depending on experiment, plot size and budget. ^{15}N is commonly used because it is non-radioactive, does not decay with time, does not pose any sort of health threat, is safe in the plant-soil system and can be used without a permit (Hauck and Bremner, 1976). However, the use of ^{15}N is not without its drawbacks. The material is very expensive therefore making studies limited to greenhouse or microplot experiments and interpretations are complicated by the fact that ^{15}N undergoes a biological interchange when applied to the soil system. This biological interchange is defined as the process in which labeled ions are replaced with non-labeled ions or vice versa by means of microbial synthesis or decomposition. For example, a labeled inorganic N molecule (fertilizer N) may be transformed to a non-labeled organic molecule through immobilization. A non-labeled inorganic molecule may then be transformed to a labeled molecule by mineralization. This labeled N may result in much lower ^{15}N excess. It is for this reason that it is often important to look at recoveries using both the difference and isotopic method (Jansson, 1958).

Another caveat often associated with ^{15}N studies is the added N interaction (ANI) or so called “priming effect”. Added N has been reported to stimulate, depress or have no effect on the mineralization of soil N. Stimulation of mineralization has been reported in experiments by Stotzky and Mortensen (1958); Broadbent (1965) and Chu and Knowles (1966). Westerman and Kurtz (1974) found that adding N increased the soil uptake of N by 17-45% in the first year of the experiment and 8-27% in the second year. The increase in plant uptake was speculated to be due to stimulation of microbial activity by N fertilizers which increased mineralization of soil N. Contrary to these findings is a depression of mineralization (Gerretsen, 1942; Megusar, 1968). Harmsen and Kolenbrander (1965) reported no change in mineralization as a result of fertilizer additions. Apparent N interactions can be real, however, if fertilizer N increases the volume of soil explored by roots (Jenkinson et al. 1985). Another cause of apparent N interactions is pool substitution. Pool substitution is the process by which added labeled N stands proxy for native unlabelled N that would otherwise have been removed by the pool. Microbial immobilization of N can either by decomposition of organic matter or decomposition of plant roots can lead to pool substitution and is the dominant cause of apparent added N interactions. Isotopic displacement reactions in which added labeled N displaces native unlabelled N from a bound pool can also lead to apparent added N interactions

(Jenkinson et al., 1985). This is likely to only be of significance in exceptional circumstances.

Despite these caveats, ^{15}N-labeled materials enable us to make unequivocal determinations of applied-N recovery in crops and soils and are used frequently to determine the fate of applied fertilizer N. Tracer techniques permit direct measurement of soil N transformations and give positive evidence that the labeled material has interacted in some manner with other nitrogenous constituents in the sample (Hauck, 1982). In the past, ^{15}N investigations were discouraged because of the high cost and associated maintenance problems for the instruments used for analysis and high cost of the labeled material.

Fried et al. (1976) described a third method of determining use efficiency. They used a steady state long-term concept. They stated that use efficiency was increased as long as a crop response to fertilizer was seen. In other words use efficiency could be described as the amount of N removed by the crop at harvest divided by the amount of fertilizer applied. In this system removal of the amount applied indicated efficient use of fertilizer N and less potential for residual N for leaching and environmental pollution.

1.7 Microplot Size

In the use of ^{15}N labeled fertilizers as tracers in a soil-plant system, the dimensions of the ^{15}N test plot (microplot) is very important. Many researchers have evaluated size and design requirements for successful microplot experiments (Jokela and Randall, 1987; Sanchez et al., 1987; Olson, 1980). Researchers are concerned with the lateral movement of ^{15}N in non-restricted or unconfined microplots. An unrestricted area of 2 m X 2 m has been suggested by many to be a suitable size (Johnson and Kurtz, 1974; Olson, 1980; Jokela and Randall, 1987; Sanchez et al., 1987). Olson (1980) demonstrated that accurate values for plant N uptake could be obtained by sampling the three center-most row plants in 2.13 m x 2.14 m unconfined corn microplots. Jokela and Randall (1987) evaluated corn plant N uptake in 0.76 m row spacing using 1.52 m x 2.29 m unconfined microplots. They found that reasonable ^{15}N recovery could be obtained if plants were sampled from the center row at least 0.38 m from the edge of the microplots. Stumpe et al. (1989) suggested sampling plants at least 0.50 m from the microplot border to avoid problems with dilution or lateral movement of N. Confined microplots use barriers placed in the soil (Malhi and Nyborg, 1983; Power and Legg, 1984) to eliminate lateral movement of labeled and unlabeled N (Ma et al., 1995). The one major advantage of using a confined microplot is that the border can prevent diffusion and mass flow of ^{15}N from inside to outside the microplot and discourage the similar movement of unlabeled N from outside to inside (Carter et al., 1967; Malhi and Nyborg, 1983; Power and Legg, 1984). The major problem with confined microplots is the time consuming nature of establishment. Most reports agree that a confined microplot size of 2 m^2 is sufficient for most experiments. Microplots must have sufficient size to allow for collection of plant and soil samples while taking into account border effects on the perimeter of the microplot area. The second important factor to consider is the expense of the ^{15}N labeled fertilizer. These two factors will dictate the size and design of the proposed research (Silvertooth et al. 1998). Another factor involved with recovery is the time at which recovery is determined. Many researchers (Carter et al., 1967; Westerman et al., 1972; Bigeriego et al., 1979; Olson, 1980) have determined recovery in the crop at the time of harvest. Recovery at harvest allows for a way to directly evaluate the efficiency of a fertilization practice.

1.8 ^{15}N Recovery

Most ^{15}N studies give estimates of recovery in the range of 30-75%. In Kentucky, Kitur et al., (1984) reported that 23-29% of the labeled N applied was found in corn grain and as N rate increased, N recovery in terms of kg ha^{-1} increased. Meisenger (1985) found 15-43% of fertilizer N was recovered in corn grain and that N recovery also increased in kg ha^{-1} as N rate increased. In Minnesota 17-18% of recovered N was found in corn grain (Gerwing et al., 1979; Timmons and Dylla, 1983). In Iowa, Timmons and Baker (1991) recovered 30-48% of labeled N in corn grain. Most ^{15}N work and N use efficiency has been done on corn in the upper Midwest and with other grain crops. Very little work has been done with cotton grown on the alluvial soils of the Mississippi River delta. Karlen et al. (1996) found that 20-34% of labeled fertilizer was recovered in seeds. After harvest, an additional 20% of applied N was found throughout the soil profile. They speculated that approximately 50% of the applied N was lost through denitrification, volatilization or leaching during the growing season (Karlen et al., 1996).

1.9 Cotton Root Growth

A prerequisite to understanding problems with fertilization is knowledge of the root development characteristics of the crop (Basset et al., 1970). The root system of a cotton plant can be quite extensive depending on soil type, available moisture and temperature. The radicle or primary root emerges rapidly and is the first organ to emerge from the seed coat. The primary root penetrates quickly and may reach depths of up to 25 cm or more by the time the cotyledons unfold. Root development during the early stages of growth may proceed at rates of 1-5 cm d^{-1} depending on soil conditions (Oosterhuis, 1990). The taproot may extend to 2.5 m on deep, irrigated soils (McMichael, 1990). Areas with high water tables and compacted soils may result in much shallower root systems (Oosterhuis, 1990). Numerous lateral roots grow outward from the taproot and these secondary roots can form a mat of roots that may extend horizontally as much as 1 m. Generally, the thinner and longer the roots, the better its geometry for the uptake of nutrients from the soil (Nilsen and Barber, 1978). The bulk of the plant root system is located in the upper 1 m of soil but distribution is largely dependent upon soil moisture, soil physical structure and plant vigor (Oosterhuis, 1990). Root distribution (defined as root length density) within the soil profile is usually about 1.60 cm cm^{-3} (Schwab et al., 2000). The total root dry weight generally composes 10-20% of the total dry weight produced during the growing season or a shoot:root ratio of 4-4.5:1. The total root length continues to increase until the maximum plant height is achieved and fruit begins to form. Root length then begins to decline as older roots die and total root activity begins to decline as carbohydrates are shifted towards the fruit (Oosterhuis, 1990). Although no significant increase in root length is observed during reproduction, there is an increase in root dry matter (Nayakekorala and Taylor, 1990).

The root density of cotton is generally low when compared to other crops and may lead to low exploitation of the soil nutrients (Brouder and Cassman, 1994). Root growth is controlled by genetic factors but is also modified by the environment as well as by soil characteristics (Brouder and Cassman, 1994). A poorly developed root system may be harmful later in the season if water becomes limiting and may potentially decrease nutrient uptake (Malik et al, 1979, Passioura, 1983; Mackay and Barber, 1984). Early season growth of roots may be affected cool moist conditions near the surface (Mackay and Barber, 1984). Water deficits and temperature effects are not the only factors affecting root growth. Toxic levels of Al and Mn as well as low levels of Ca and P are also known to limit root growth (Adams and Pearson, 1970; Barber, 1984; Rosolem et al., 1998). Soil impedance can also cause root systems to be shallow and insufficient (Barley et al., 1965; Pearson et al., 1970). Because it is known that root extension is important to plant growth, numerous studies have been conducted to determine the factors affecting growth. Isolating and measuring root systems involves considerable labor making root studies difficult and time consuming. This is particularly true for deeper rooting plants such as cotton. Types of studies to determine root density include total root excavation (Brown et al., 1932; Collings and Warner., 1927; Hubbard and Hebert., 1933)., tracer techniques with ^{32}P to measure the root distribution of different crop species (Hammes et al., 1963; Basset et al., 1970), rhizotron (Taylor, 1969; Taylor and Klepper, 1974) and core sampling (Kennedy et al., 1987; Schwab et al., 2000). Regardless of the technique used, studies involving root growth are difficult and results are often highly variable.

Roots require adequate nutrients for growth and development and roots tend to proliferate in zones containing fertilizer. However, roots that come into contact with fertilizer may become damaged and end up shorter than untreated roots. Increasing the N level favors shoot growth in relation to root growth and high N may allow shoots to utilize available carbohydrates and increase top growth. Also a greater N supply tends to increase auxin levels and may actually inhibit root growth. Nitrogen fertilization does increase total dry weight of shoots and roots and this increase in above ground growth may produce a greater leaf area earlier and provide more photosynthate for roots later in the season. These larger plants may have roots that profuse deeper into the soil allowing for better water uptake (Gardener et al., 1985). Because of the importance of early season root growth in cotton, many studies have been conducted to evaluate the use of starter fertilizers and plant growth regulators (PGR's) (Kovar and Funderburg. 1992; Hutchinson and Howard, 1997; Stewart and Edmisten, 1998; Howard et al., 1999). Starter fertilizers generally contain N and phosphorus (11-37-0) with the majority being phosphorus (Hutchinson and Howard, 1997; Stewart and Edmisten, 1998; Howard et al., 1999). It is generally thought that preplant rates of N stimulate vegetative growth and phosphorus stimulates root growth.

Previous studies have shown that crop response to starter fertilizers varies with year, tillage system, soil type, method of application, rate and nutrient concentrations within the starter (Howard et al., 1999). High rates of N at planting has often times shown a decrease in the root:shoot ratio. Murata (1969) showed that 90% of photosynthate was partitioned to shoots of rice when grown under high N conditions. However, plants grown under low N conditions tended to partition only 50% of their photosynthate to shoot. It is generally thought that new shoot growth stimulated by increased N acts as a stronger sink for photosynthate than roots under these conditions (Murata, 1969). As a rule, tops are favored when water and N are plentiful but roots are favored when these factors are limited. Zhang et al., (1998) found that grapefruit trees grown under irrigation in poorly drained soils responded with larger fibrous roots systems after application of large amounts of NH_4N0_3. Although this information disputes claims that root growth is inhibited by high N rates, it may explain the response of cotton plants to large amounts of fertilizer N applied to cotton grown on low oxygen, poorly drained clay soils.

CHAPTER 2

RESIDUAL AND APPLIED N EFFECTS ON N FERTILIZER EFFICIENCY, PARTIONING AND YIELD OF COTTON IN ROTATION WITH CORN

2.1 Introduction

Recently, much of the land previously monocropped to cotton in the Midsouth has been shifted to corn. Reasons for this shift in acreage include rotational benefits, relative ease of corn production compared to cotton and economic factors due primarily to the Freedom to Farm Bill. Nitrogen recommendations for corn production are not unlike those for cotton and are often based on climate, soil classification, and yield goals (Voss 1982). Louisiana currently recommends156-280 kg N ha^{-1} for corn yields of 8400 kg ha^{-1}. The upper range of fertilization is for soils with a higher clay content and those soils that are irrigated (Mascagni and Burns, 2000) but generally 168 kg N ha^{-1} is sufficient in most years (Boquet et al., 2001). Although corn demands large amounts of N fertilizer, the plant does not always utilize all applied N. Because overfertilization does not generally adversely affect corn yield, producers often apply more than the recommended rate of N to non-irrigated corn in anticipation of adequate rainfall. During dry years, large amounts of fertilizer N may remain in the soil after harvest.

Depending on grain yield, N rate, tillage practices application methods and soil type, as much as 50% of the applied N may remain in the soil after grain removal (Kitur et al., 1984; Sanchez and Blackmer, 1988; Timmons and Cruse, 1990). Large amounts of residual N are not limited to dry land production.

Bigeriego et al. (1979) found that from 4 to 40% of labeled ammonium sulfate was still in the soil after irrigated corn harvest.

The residual N remaining after a non-optimal corn yield has the potential to create problems associated with excess N in the subsequent crop rotation. Although cotton demands moderate amounts of N for optimum yields, excessive N may induce excessive vegetative (rank) growth. This growth, depending upon harvest conditions, may result in reduced yields (Maples and Keogh, 1977).

Nitrogen for crop production is derived from other sources in addition to N fertilizer. Because sources of N other than applied N are available, ^{15}N-labeled materials have been used to determine the fate of applied fertilizer N. Tracer techniques permit direct measurement of soil N transformations and give positive evidence that the labeled material has interacted in some manner with other nitrogenous constituents in the sample (Hauck and Bremner 1976, Hauck 1982). The ability to determine how efficiently cotton utilizes fertilizer N following potentially high amounts of residual N could aid in choosing the correct N rate when following corn.

The objectives of this experiment were i) to determine effect of residual and applied N on cotton yield and partitioning of yield components ii) determine the effects of residual and applied N on N and dry matter accumulation and iii) determine fertilizer N use efficiency of cotton when following corn in rotation.

2.2 Materials and Methods

A field study was conducted at the Northeast Research station near St. Joseph, LA in 1999 and 2000. The study was conducted on a well-drained

Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent) using a cotton and corn rotational study initiated in the spring of 1996. The corn and cotton were in the third year of rotation. The rotational study utilized a randomized complete block design with a factorial arrangement of treatments and five replications to determine residual N effects of the previous crop on yield. Fertilizer N rates of 0, 168, 224 and 280 kg ha^{-1} were evaluated in the corn. Following each corn N rate, cotton was supplied with N rates of 0 28, 56, 84 112 and 140 kg ha^{-1} were applied to the cotton the following year. The N tracer component of our study used only corn N rates of 0, 168, and 280 kg ha^{-1} factorially arranged with cotton N rates of 0, 56 and 112 kg ha^{-1}. These rates were chosen based on typical N rates used by farmers in this particular area and costs associated with ^{15}N. Cotton cv. 'SG 125' (Delta and Pine Land Company, Scott, MS) was planted on 30 April 1999 and 5 May 2000 at a seeding rate to achieve a plant population of approximately 100,000 plants ha^{-1}. Each existing plot consisted of four 1 m-wide rows, 13.7 m long. Conventional tillage was used in both years and, management was consistent with typical agronomic practices used in dryland cotton production, with the exception of fertilization. Once the plants reached the 4-5 true leaf stage (25-30 DAP), microplots (2 m long x 1 m wide) were established within existing plots (Fig. A1). Microplots were contained using borders fashioned out of galvanized sheet metal (22 gauge) and enclosed one row. Borders were placed 30 cm deep around the microplot to discourage any movement of the labeled fertilizer. Plants within microplots were hand thinned to achieve a uniform population of 20 plants per microplot. Once the microplots had been established, an aqueous N fertilizer solution in the form of 5 Atom % ^{15}N double labeled NH_4NO_3 (Icon Isotopes, Summit, NJ) at rates of 56 and 112 kg N ha^{-1} was applied using a re-pipette syringe (Fig. A2) in a manner to simulate sidedressing. Solution was applied about 15 cm from and parallel to the seed drill and about 7.5 cm deep. Each plot received 100 ml of the fertilizer solution in 20, 5 ml injections every 18.5 cm. The remainder of the cotton outside of the microplot was fertilized with NH_4NO_3 using hand spreaders. Weeds, as well as leaves, fruit, and other plant parts shed throughout the growing season, were collected and analyzed at the end of the season. Cotton was defoliated when 60% of the bolls had opened. After most leaves had fallen and been collected and cotton was ready to harvest, all cotton plants within the microplot were removed. Seedcotton was removed and partitioned using boxmapping techniques (Jenkins and McCarty, 1995). Each plant was divided into leaves, bolls and branches. Bolls were further divided into carpel walls, lint and seed. Before ginning, bolls were grouped into vertical horizons to determine a temporal and positional effects on yield. Plants were sectioned into three horizons: Horizon 1 (mainstem nodes 4-8), Horizon 2 (mainstem nodes 9-12) and Horizon 3 (mainstem nodes 13+). Each horizon was additonally proportioned to boll location on sympodia. Each sample was oven dried at 65^{o}C for 48 hours and weighed. Seedcotton samples were ginned and seed were acid de-linted before drying. Oven dried seed samples were ground using a small coffee grinder (Braun Model KSM 2) and sieved to pass a 0.5 mm screen. All other plant tissue samples were ground using a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass a 0.5 mm screen. To prevent any cross-contamination, all grinding equipment was thoroughly cleaned between samples. Subsamples of ground tissue were analyzed for total N using a LECO FP 428 N analyzer (LECO, St. Joseph, MI). Subsamples were then analyzed for ^{15}N excess using a Finnigan DeltaPlus (Finnigan, San Jose, CA) mass spectrometer interfaced with an elemental analyzer (NC 2500) (CE Instruments). Natural abundance levels of ^{15}N were determined from untreated controls and calculations of ^{15}N recovery were done using the following calculations:

1000(Total N in plant sample x excess ^{15}N % in plant sample)= mg ^{15}N in sample

100 (mg ^{15}N in plant sample / mg ^{15}N added to plot) = % recovery for plant sample

100 (total mg ^{15}N recovered in plot / mg ^{15}N added to plot) = % total ^{15}N Recovery

% ^{15}N Recovered X Total N applied = Nitrogen derived from fertilizer (Ndff)

Total N Assimilated – Ndff= Nitrogen derived from soil (Ndfs)

After cotton was harvested, soil samples for N analyses were taken in each microplot. Six 2.54 cm x 30 cm soil cores were taken within the microplot. Three samples were taken approximately 15 cm from each side of the crop row. Samples were combined, air dried and stored for analysis. To determine soil N within the profile, two 5 cm diameter soil cores were taken with a Giddings probe (Giddings Machine Company, Fort Collins, CO) in the fertilizer band to a depth of

1.22 m. Each core was partitioned into 15 cm increments and corresponding increments were combined prior to N analysis. Samples were air dried and placed in storage until analysis. Soil samples were analyzed for total N using a Leco FP 428 N analyzer and Kjeldah analysis. Data were analyzed using analysis of variance procedures (PROC GLM) (SAS, 2000). Means were separated using the LSMEANS procedure and Fisher's Protected LSD (p=0.05).

2.3 Results

Monthly rainfall and temperature data along with 70 year averages were recorded and are shown in table 2.1.

Table 2.1. Rainfall and average air temperature data for Northeast Research Station, St. Joseph, LA, 1998-2000.

	Rainfall				Air Temperature			
	1998	1999	2000	70 Year Avg.	1998	1999	2000	70 Year Avg.
	-------------cm month^{-1}-------------				------------------^{o}C-----------------			
April	7.5	6.7	19.5	12.5	18	22	18	19
May	1.1	7.2	5.4	12.4	26	24	26	23
June	12.2	9.3	7.0	9.3	29	28	27	27
July	15.7	3.5	4.5	10.8	30	29	29	28
August	4.5	11.6	5.5	8.2	29	29	29	28
September	6.9	7.3	6.6	6.8	27	24	26	24

2.3.1 Cotton and Corn Yield

Corn yields varied among years and were largely dependent upon rainfall (statistics not shown) and N rates. Corn yields were drastically reduced when no fertilizer N was applied. Previous cotton N rate had little residual effect (Table 2.2). Corn yields responded to increased N up to 280 kg N ha^{-1} in the 1998 study but in the following years 168 kg N ha^{-1} was sufficient for optimum yields (Table 2.2). Because rainfall was the major contributing factor in corn yield and increasing N rates over 168 kg N ha^{-1} did not significantly increase yield, the low yields in 1998 and 1999 provided the probability that large amounts of residual fertilizer N were present.

Table 2.2. Effect of residual and applied N rates on corn grain yields grown in rotation with cotton, 1997-2000.

		Grain Yield				
N Rate		Year				
Corn	Cotton	1997	1998	1999	2000	4 Year Avg.
		kg ha^{-1}				
0	0	2658 d†	1038 d	1752 d	2247 b	1925 b
0	56	2850 d	859 d	1618 d	1967 b	1824 b
0	112	3187 d	1141 d	2451 d	2630 b	2353 b
168	0	10304 c	7352 c	8618 a	6368 a	8161 a
168	56	10567 bc	7514 c	8055 abc	6305 a	8110 a
168	112	10592 bc	7660 c	7735 bc	6268 a	8065 a
280	0	11412 a	8416 b	7349 c	6930 a	8528 a
280	56	10979 ab	8526 ab	7949 abc	6672 a	8532 a
280	112	10488 bc	9005 a	8536 ab	6653 a	8672 a

†Data were analyzed by years. Means within a column sharing the same letter do not differ significantly according to the least squares means test ($p \leq 0.05$).

Cotton yields in this particular test have been exceptional since its inception with seedcotton yields over 4000 kg ha^{-1}. After three cropping seasons, yields of plots receiving no N fertilizer were still above 2500 kg ha^{-1} (Table 2.3). Unlike corn, cotton response to fertilizer N varied with perceived residual N from the previous crop. Cotton following 0 N exhibited a quadratic yield response and yields increased with each increasing rate of applied N (Figure 2.1).

Table 2.3. Effect of residual and applied N on seedcotton yield of cotton cv. SG 125 grown in rotation with corn, 1997-2000.

		Seedcotton Yield				
		Year				
Corn N Rate	Cotton N Rate	1997	1998	1999	2000	4 Year Avg.
kg ha^{-1}						
0	0	2667 e[†]	2723 c	2775 f	2918 c	2771 d
0	56	3002 de	3633 a	3409 cd	4380 ab	3606 b
0	112	3249 cd	3851 a	3852 ab	4643 a	3899 ab
168	0	3350 bcd	2853 bc	3008 ef	3632 bc	3211 c
168	56	3360 bcd	3714 a	3281 de	4390 ab	3686 b
168	112	3851 ab	3910 a	3783 ab	4291 ab	3959 ab
280	0	3692 abc	3119 b	3628 bc	4176 ab	3654 b
280	56	3994 a	3842 a	4015 a	4384 ab	4059 a
280	112	3845 a	3806 a	4020 a	4088 ab	3940 ab

[†] Data were analyzed by years. Means within a column sharing the same letter do not differ significantly according to the least squares means test ($p \leq 0.05$).

As N applied to previous corn crop increased (presumably more residual N), cotton response to applied N diminished with increasingly greater Y intercepts and lower slopes for the response curve (Fig. 2.1). The effect of residual N was apparent following 280 kg corn-applied N ha^{-1} with cotton receiving 0 N at yielding at planting. This treatment yielded 883 kg ha^{-1} more seedcotton than the unfertilized control. Maximum yields were obtained with very little applied fertilizer N with yields declining as N rates reached 112 kg N ha^{-1} (Fig. 2.1). These data proved that little benefit was gained by adding large amounts of preplant N following high N rates from the previous year but did not reveal the processes involved or N rates that would be most effective under these conditions.

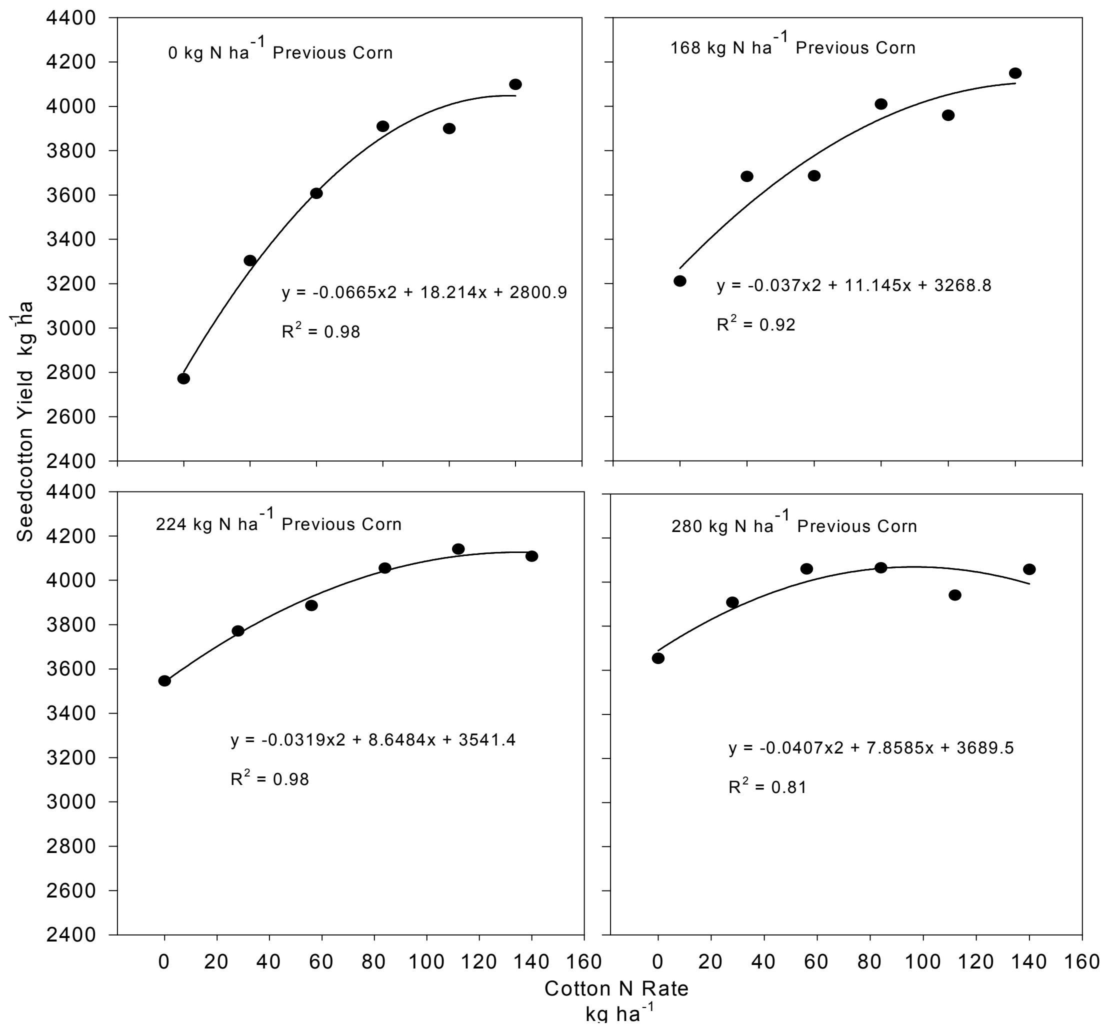

Figure 2.1. Effect of previous fertilizer rate on yield response of cotton cv. SG 125 grown in rotation with corn to various rates of applied N, 1997-2000. 4 Year average.

2.3.2 Yield Distribution of Seedcotton

Yield partitioning showed a trend of increasing seedcotton yield in the upper horizons in 1999 with increasing previous fertilizer rates (Table 2.4.). In 1999, unfertilized plots partitioned 31, 45 and 13 percent of yield in the 1st, 2nd and 3rd horizons, respectively with the remainder of yield accounted for by vegetative bolls. However, with the presumed increase in residual N available from the previous corn-applied N rate of 168 kg ha^{-1} yield increased because of more productivity from fruiting positions developing later in the season (Table 2.4). Cotton receiving 0 N at planting following 280 kg corn-applied N ha^{-1} followed the same trend, as total seedcotton increased and more (33%) was found in the third horizon (Table 2.4). With the addition of preplant N to the cotton crop, the effect of the residual N from the corn crop diminished. Only the residual N remaining after a 280 kg corn-applied N ha^{-1} influenced yield distribution when 56 kg N ha^{-1} was applied to cotton (Table 2.4). In that case, over 48% of the total yield was found in Horizon 3 compared to 28 and 27% when following residual N from 0 and 168 kg corn-applied N ha^{-1}, respectively. Increasing the cotton-applied N application to 112 kg N ha^{-1} shifted yield distribution upwards on the plant and was not necessarily influenced by residual N from the previous crop. However, this shift was still enhanced in one instance by residual N effects with a 39% increase in seedcotton at position one in the 3rd horizon when following 280 kg corn-applied N ha^{-1} compared to 0 corn-applied N. (Table 2.4).

Increases in seedcotton, especially in the upper third of the plant resulted from increases in boll number (r=0.82) and to a lesser extent seedcotton per boll (0.50). Boll number in the lower third of the plant canopy (Horizon 1) was depressed with increasing corn-applied N as well as cotton-applied N (Table 2.5) probably because of large plants and self shading. A greater proportion of total yield of plants receiving 56 or 112 kg cotton-applied N ha^{-1} following 280 kg

Table 2.4. Effect of residual and applied N on seedcotton yield distribution of cotton cv SG 125 grown in rotation with corn, 1999.

N Rate			Horizon 1†			Horizon 2			Horizon 3			
Corn	Cotton	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
----kg ha^{-1}----		----------g m^{-2}§----------										
0	0	25.2	55.5	15.1	4.6	88.0	14.2	6.1	26.8	3.2	0.5	239.1
168	0	12.2	63.7	13.8	1.7	85.5	12.7	9.3	57.5	15.0	0.0	271.3
280	0	19.2	53.0	25.6	5.7	82.2	31.1	15.5	96.3	16.7	1.9	347.1
0	56	30.3	39.3	26.9	3.4	105.3	27.8	8.4	82.6	11.7	1.4	337.0
168	56	22.1	43.1	20.9	7.6	92.3	32.0	9.5	64.6	17.1	1.1	310.2
280	56	10.9	30.1	15.6	7.3	81.2	32.5	23.1	135.3	45.7	3.0	384.5
0	112	21.6	39.7	19.2	6.2	95.1	46.6	19.0	97.8	36.5	3.7	385.2
168	112	14.2	33.9	15.5	6.0	85.2	23.5	24.0	110.2	24.5	11.9	348.8
280	112	13.2	30.2	17.8	10.2	81.2	38.4	21.2	136.0	36.0	4.5	388.5
LSD (0.05)		NS¶	NS	NS	NS	NS	14.0	NS	39.8	20.1	6.4	60.8

† Horizon 1=Mainstem node (MSN) <9, Horizon 2=MSN 9-12, Horizon 3=MSN >12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Determined by boxmapping procedure of all plants removed from a confined 2 m^2 microplot at harvest.
¶ NS=Non-significant according to Fisher's Protected LSD ($p \leq 0.05$).

corn-applied N ha^{-1} resulted from an increase in the number of bolls in the third horizon (Table 2.5). Second and third position boll number was significantly increased for plants receiving 56 or 112 kg cotton-applied N ha^{-1} following 280 kg corn-applied N. Although this increase in boll number resulted in an increase in yield, the added weight in the upper portion of the canopy caused plants to lodge.

Yield was much more evenly distributed in 2000. Yield distribution in the first and second horizon in plots receiving no N at planting was not affected by corn-applied N rate (Table 2.6). However, cotton following 280 kg corn-applied N ha-[1] contained 21% of total yield in the third horizon compared to 8 and 18% when following 0 and 168 kg corn-applied N ha^{-1}, respectively (Table 2.6).

Table 2.5. Effect of residual and applied N on temporal and spatial distribution of bolls of cotton cv. SG 125 grown in rotation with corn, 1999

N Rate			Horizon 1†			Horizon 2			Horizon 3			
Corn	Cotton	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
----kg ha^{-1}----												boll m^{-2}§-
0	0	7.4	14.0	4.2	1.4	22.7	4.5	1.9	7.9	1.2	0.2	65.0
168	0	3.7	16.0	3.7	0.5	20.4	3.9	2.9	16.0	4.2	0.0	82.2
280	0	5.2	12.4	6.2	1.7	17.5	7.4	4.4	23.9	4.7	0.7	90.9
0	56	7.4	9.5	7.2	1.2	23.5	6.5	2.4	21.0	3.0	0.7	71.0
168	56	5.7	10.0	5.4	2.0	21.0	8.4	2.5	19.4	5.3	0.4	80.1
280	56	2.7	7.2	4.0	2.2	17.9	7.9	5.5	29.9	11.7	1.0	79.2
0	112	5.2	10.0	4.9	1.5	19.9	11.7	4.7	24.7	7.7	0.9	83.7
168	112	3.2	7.9	3.9	1.4	17.9	5.0	5.9	25.4	6.0	3.0	89.7
280	112	2.9	7.7	4.2	2.9	17.9	8.5	6.0	32.9	10.2	2.0	94.9
LSD (0.05)		NS¶	NS	NS	NS	NS	3.9	NS	8.3	4.9	1.9	14.1

† Horizon 1=Mainstem node (MSN) <9, Horizon 2=MSN 9-12, Horizon 3=MSN >12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Determined by boxmapping procedure of all plants removed from a confined 2 m^2 microplot at harvest.
¶ NS=Non-significant according to Fisher's Protected LSD ($p \leq 0.05$).

Yield advantages of plots following 168 or 280 kg corn-applied N ha^{-1} over that of the control resulted from increased seedcotton weight from outer fruiting positions (pos 2 and 3). Previous corn-applied N rate had less of an effect on yield distribution when fertilizer N was added than in 1999. Yield distribution of plots receiving 168 kg corn-applied N ha^{-1} followed by 56 kg cotton-applied N ha^{-1}

at planting in 2000 was similar to that for plants receiving 0 cotton-applied N in 1999 (Table 2.5).

Table 2.6. Effect of residual and applied N on temporal and spatial distribution of seedcotton yield of cotton cv. SG 125 grown in rotation with corn, 2000.

N Rate			Horizon 1†			Horizon 2			Horizon 3			
Corn	Cotton	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
----kg ha^{-1}----		---------g m^{-2}§---------										
0	0	22.1	89.3	18.5	6.4	85.7	21.0	2.7	20.5	0.7	0.0	266.8
168	0	15.4	90.4	24.3	10.2	106.1	25.3	5.1	49.2	9.3	1.6	336.8
280	0	33.5	88.8	33.3	9.9	104.4	45.5	7.5	72.9	12.0	2.2	409.8
0	56	37.5	89.1	32.3	11.3	97.0	31.6	8.8	59.6	8.5	0.0	375.5
168	56	32.8	122.2	34.3	8.4	120.6	38.2	10.8	59.2	5.8	0.5	432.6
280	56	46.9	84.4	34.3	10.0	96.3	39.1	5.8	64.3	10.9	0.6	392.4
0	112	33.1	98.6	30.4	16.0	118.9	46.7	12.7	80.2	10.4	0.5	447.3
168	112	20.4	102.0	36.8	15.4	96.2	35.3	10.7	74.4	15.2	2.8	409.0
280	112	21.2	93.3	42.6	8.1	95.0	36.5	6.6	75.2	17.2	3.1	398.6
LSD (0.05)		NS¶	NS	NS	NS	NS	15.0	NS	NS	NS	NS	24.7

† Horizon 1=Mainstem node (MSN) <9, Horizon 2=MSN 9-12, Horizon 3=MSN >12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Determined by boxmapping procedure of all plants removed from a confined 2 m^2 microplot at harvest.
¶ NS=Non-significant according to Fisher's Protected LSD ($p \leq 0.05$).

Seedcotton in the first, second and third horizons accounted for 36, 38 and 17 % of total yield and there was no significant difference in distribution following 168 or 280 kg corn-applied N ha^{-1} (Table 2.6). Increasing cotton-applied N to 112 kg N ha^{-1} did not cause a significant difference in seedcotton distribution following 0, 168 or 280 kg corn-applied N ha^{-1} (Table 2.6). On average, 35, 37 and 22% of total seedcotton yield was found in the first, second and third horizons, respectively. Yield was proportioned more equally among the horizons resulting in a much yield in Horizon 1 than in 1999. Cotton receiving cotton-applied N in 1999 accumulated only around 10% of total yield in the first horizon compared to over 20% in 2000. Increased seedcotton in Horizons 1 and 2, along with decreased shed squares and bolls ultimately increased final yield.

Table 2.7. Effect of residual and applied N on temporal and spatial distribution of bolls of cotton cv. SG 125 grown in rotation with corn, 2000

N Rate			Horizon 1†			Horizon 2			Horizon 3			
Corn	Cotton	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
----kg ha^{-1}----		-------------------------------------boll m^{-2}§-----------------------------------										
0	0	5.7	18.5	4.7	2.0	21.0	6.0	0.7	5.7	0.2	0.0	64.4
168	0	4.0	18.0	5.5	2.7	23.0	6.7	1.7	11.9	2.9	0.7	76.9
280	0	8.4	17.7	7.2	2.5	21.5	10.2	1.7	16.4	2.7	0.5	88.5
0	56	8.7	17.4	7.4	3.2	22.0	7.5	2.0	14.0	2.4	0.0	84.4
168	56	8.4	23.7	7.7	2.2	25.0	9.0	2.4	13.4	1.5	0.2	93.2
280	56	10.5	17.4	7.5	2.4	20.0	9.5	1.7	14.9	2.9	0.2	86.7
0	112	7.0	19.9	6.5	3.5	24.7	11.0	3.0	18.4	2.7	0.2	96.7
168	112	5.2	19.2	8.2	4.2	22.2	9.5	3.0	18.5	3.7	0.9	94.4
280	112	4.7	18.7	9.0	1.7	21.0	8.9	1.5	17.0	4.5	1.0	87.9
LSD (0.05)		NS¶	NS	NS	NS	NS	3.3	NS	NS	NS	NS	10.7

† Horizon 1=Mainstem node (MSN) <9, Horizon 2=MSN 9-12, Horizon 3=MSN >12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Deteremined by boxmapping procedure of all plants removed from a confined 2 m^2 microplot at harvest.
¶ NS=Non-significant according to Fisher's Protected LSD (p≤0.05).

Although deleterious effects did not occur in either year of the study, the greater % of total seedcotton in Horizon 3 found in 1999 could have led to potentially harmful effects such as increased insect damage, delayed maturity, boll rot and decreased harvesting efficiency.

2.3.3 Dry Matter Accumulation

Total dry matter accumulation was similar for both years and previous corn-applied N rate along with an increase in cotton-applied N increased total dry matter production in both years of the study (Table 2.8). With the exception of branches, all data were pooled for 1999 and 2000. Total dry matter accumulation ranged from a low of 7635 kg ha^{-1} in the unfertilized treatment to 11203 kg ha^{-1} in plots receiving 280 kg corn-applied N ha^{-1} followed by 56 kg N ha^{-1}. Dry matter tended to be similarly distributed among plant parts with little difference in distribution between fertilizer treatments. Seedcotton and branches accounted for most of total dry matter each year. Although seedcotton yield was affected by both previous and applied N, the percentage of total dry matter accounted for by seedcotton was similar for all treatments. Larger plants increased the amount of plant material abscised in 1999 but this component was only 9-10% of total dry matter. Shed material decreased in 2000 presumably because of smaller plants and less shading. A significant year x corn N x cotton N interaction occurred for branches and data were compared between and among years (Table 2.8). Larger plants in 1999 resulted in a greater accumulation of dry matter in branches than in 2000. Branch weight tended to increase with increasing N indicating increased plant size as a response to a larger N pool. Leaves accounted for approximately 20% of total dry matter but few differences were seen among treatments. The 2000 crop partitioned more dry matter into seedcotton than in the 1999 crop. Thirty to 35% of the total dry matter was found in the seedcotton compared to 28% from 1999. Alternatively,

Table 2.8. Effect of residual and applied N on total dry matter accumulation of cotton cv. SG 125 grown in rotation with corn, 1999-2000.

N Rate			Plant Component†						
Year	Corn	Cotton	Seed	Lint	Burs	Branches	Leaves	Shed	Total
					kg N ha^{-1}-				
1999	0	0	1173	983	968	2206 gh	1638	735	7703
2000	0	0	1240	1489	965	1988 h	1628	257	7567
Avg.‡			1207 d§	1236 b	967 c	-------¶	NS#	NS	7635 d
1999	168	0	1312	1128	1026	2543 fgh	1818	776	8603
2000	168	0	1612	1433	1188	2429 fgh	1701	292	8655
Avg.			1462 c	1281 b	1107 bc	-------	NS	NS	8629 c
1999	280	0	1625	1382	1313	3476 bcde	2139	862	10797
2000	280	0	1949	1454	1394	3120 cdef	1980	315	10212
Avg.			1787 b	1418 b	1354 ab	-------	NS	NS	10504 ab
1999	0	56	1665	1314	1275	3601 bcd	2068	1054	10977
2000	0	56	1796	1692	1331	2563 fgh	1804	270	9456
Avg.			1731 b	1503 ab	1303 b	-------	NS	NS	10216 b
1999	168	56	1552	1219	1204	2822 efg	1961	985	9743
2000	168	56	2066	1659	1471	2866 defg	1934	276	10272
Avg.			1809 b	1439 ab	1338 b	-------	NS	NS	10008 b
1999	280	56	1902	1731	1464	4466 a	2223	938	12724
2000	280	56	1883	1693	1327	2594 fgh	1913	272	9682
Avg.			1893 ab	1712 a	1396 ab	-------	NS	NS	11203 a
1999	0	112	1955	1536	1530	4060 ab	2182	961	12224
2000	0	112	2136	1361	1509	2885 defg	1903	302	10096
Avg.			2046 a	1449 ab	1520 a	-------	NS	NS	11160 a
1999	168	112	1801	1396	1242	2868 defg	1869	862	10038
2000	168	112	2004	1762	1465	2735 efgh	2083	288	10337
Avg.			1903 ab	1579 a	1354 ab	-------	NS	NS	10188 b
1999	280	112	1948	1478	1488	3652 bc	1982	949	11497
2000	280	112	1927	1637	1325	2740 efgh	2292	265	10186
Avg.			1938 ab	1558 a	1407 ab	-------	NS	NS	10842 ab

†Samples were taken prior to harvest from all plants within a confined 2 m^2 microplot
‡Means averaged across two years
§Averages within a column sharing the same letter do no differ according to the least squares means test (p=0.05)
¶ A significant year X corn N X cotton N interaction occurred and means were averaged across years. Means within a column sharing the same letter are not different according to the least squares means test (p0.05)
# NS=Non-significant according to Fisher's Protected F-test

dry matter accumulation in the branches was only 28% of total dry matter in 2000 compared to 31% in 1999 but reproductive partitioning of total dry matter was higher. Overall plant size was also smaller in 2000 compared to 1999 in all fertilizer treatments. The more compact plants resulted in less self-shading and total abscised material (shed). This decrease in plant size and more evenly distributed fruit increased the overall harvest index to 41% compared to 33% in 1999.

2.3.4 Total N Assimilation

As with dry matter, total N assimilated increased as both corn- and cotton-applied N increased. Unfertilized plots assimilated 90.3 kg N ha^{-1} (Table 2.9). Residual N contribution was apparent in that cotton receiving 0 cotton-applied N at planting assimilated 20% more N than the control when following a previous corn N rate of 168 kg corn-applied N ha^{-1} (Table 2.9). Residual N from the 280 kg corn-applied N ha^{-1} corn rate increased total N assimilation of cotton receiving 0 cotton-applied N at planting 46% over the control. Residual N effects generally decreased with the addition of cotton-applied N (Table 2.9). Application of 56 kg cotton-applied N ha^{-1} at planting following 168 kg corn-applied N ha^{-1} N had similar total N as cotton following 0 corn-applied N (Table 2.9). However, residual N from the 280 kg corn-applied N ha^{-1} corn rate increased total N assimilated in plots receiving 56 kg cotton-applied N ha^{-1} at planting 24% and 16% over the 0 and 168 kg N ha^{-1} corn applied N. Residual N had the least effect on cotton receiving 112 kg cotton-applied N ha^{-1} at planting. Total N assimilated for this treatment was similar regardless of previous corn-applied N

Table 2.9. Effect of residual and applied N on total N assimilated in above ground biomass of cotton cv. SG 125 grown in rotation with corn, 1999-2000.

	N Rate		Plant Component†					
Year	Corn	Cotton	Seed	Burs	Branches	Leaves	Shed	Total
	---				$kg\ ha^{-1}$		---	
1999	0	0	42.5	5.1 g¶	14.1 gh	22.5	9.3 d	93.5
2000	0	0	54.3	3.7 g	9.1 I	16.4	3.6 e	87.1
Avg.‡			48.4 e§	-------	-------	19.5 e	-------	90.3 e
1999	168	0	51.3	5.9 fg	15.8 fg	22.0	11.4 cd	106.4
2000	168	0	76.0	5.8 g	12.5 h	19.5	4.6 e	118.4
Avg.			63.7 d	-------	-------	20.8 de	-------	112.4 d
1999	280	0	66.3	8.4 def	24.8 b	35.3	13.7 bc	148.5
2000	280	0	110.1	12.4 bc	23.1 bc	32.0	5.5 e	183.1
Avg.			88.2 c	-------	-------	33.7 bc	-------	165.8 c
1999	0	56	72.5	8.2 def	20.5 cde	31.8	16.2 ab	149.2
2000	0	56	93.2	7.7 ef	16.3 fg	23.2	4.4 e	144.8
Avg.			82.9 c	-------	-------	27.5 cde	-------	147.0 c
1999	168	56	74.8	8.7 de	18.1 ef	31.3	14.9 b	147.8
2000	168	56	113.3	9.8 cde	19.8 de	27.6	4.9 e	175.4
Avg.			94.1 bc	-------	-------	29.5 bcd	-------	161.6 c
1999	280	56	97.7	13.3 b	30.8 a	39.4	17.9 a	199.1
2000	280	56	114.7	14.2 b	21.7 bcd	32.7	5.6 e	188.9
Avg.			106.2 ab	-------	-------	36.1 abc	-------	194.0 ab
1999	0	112	94.0	12.2 bc	27.9 a	36.5	15.3 b	185.9
2000	0	112	122.7	10.5 cd	20.0 cde	28.2	5.2 e	186.6
Avg.			108.4 a	-------	-------	32.4 bc	-------	186.3 b
1999	168	112	92.3	13.8 b	24.2 b	39.0	16.2 ab	185.5
2000	168	112	119.0	13.6 b	18.8 ef	35.9	5.4 e	192.7
Avg.			105.7 ab	-------	-------	37.5 ab	-------	189.1 b
1999	280	112	101.7	20.1 a	29.1 a	39.8	18.2 a	208.9
2000	280	112	119.0	13.3 b	24.7 b	49.1	5.2 e	211.3
Avg.			110.4 a	-------	-------	44.5 a	-------	210.1 a

†Samples were taken prior to harvest from all plants within a confined 2 m^2 microplot

‡Means averaged across two years

§Averages across years within a column sharing the same letter do no differ according to the least squares means test ($p \leq 0.05$).

¶ A significant year X corn N X cotton N interaction occurred and means were evaluated by year. Means within the column sharing the same lower case letters were not significantly different according to the least squares means test ($p \leq 0.05$).

rate with one exception. Cotton following 280 kg corn-applied N ha^{-1} assimilated 10% more than cotton following 0 N or 168 kg corn-applied N (Table 2.9).

Seed were the predominant sink for N assimilation in both years accounting for 45-50% of total N in 1999 and 56-65% in 2000 (Table 2.9). Distribution of N was similar for all other plant tissues for both years of the study. Previous corn-applied N rate along with additional N applied at planting enriched plant tissues such as burs and branches. In general, branches accounted for 15% of total N in 1999 compared to only 10% in 2000. Nitrogen assimilation in leaves was similar for both years and generally increased with increasing amounts of residual and applied N comprising 20% of total N assimilated on average. The increased amount of abscised plant material in 1999 led to a loss of 10% of the total N assimilated compared to 4% in 2000. Increased seedcotton yield and a decreased amount of N lost through abscised structures were the primary reasons for the general increase in total N assimilation. Nitrogen removed in seedcotton at harvest increased with increasing residual and applied N in 1999. However, N removed at harvest was similar for all treatments except those receiving 0 N at planting following 0 or 168 kg N ha^{-1} previous corn N in 2000. The effect of corn-applied N rate on total N assimilation was evident especially when corn-applied N rates increased. Residual N was most apparent following the 280 kg N ha^{-1} corn treatment, especially with the 0 and 56 kg N ha^{-1} cotton rates. Residual effects appeared to be masked with addition of cotton-applied N (112 kg N ha^{-1}). This led to the question of how efficient is the uptake of cotton-applied fertilizer N, especially following large corn-applied N.

2.3.5 Recovery of ^{15}N Labeled N

Recovery of applied ^{15}N was affected by corn-applied N rate and residual N in both years. Total ^{15}N recovery ranged from 40-53% in 1999 and 30-59% in 2000 (Table 2.10). Recovery of labeled N was higher when cotton-applied N followed 0 or 168 kg N ha^{-1} corn-applied N than 280 kg corn-applied N in both years. Labeled N recovery increased as previous corn yields increased and decreased as previous corn yields decreased (Table 2.10). Recovery of labeled N when 56 kg cotton-applied N ha^{-1} followed 0 or 168 kg corn-applied N ha^{-1} was similar in both 1999 and 2000. However, recovery following 168 kg corn-applied N ha^{-1} increased in 2000 primarily because of increased seedcotton yield and perhaps less residual N in these treatments due to increases in grain yield. Residual N was presumed low following 168 kg corn-applied N ha^{-1} since N removed at harvest would be 66% of the amount of N applied (N removed ha^{-1} =1.3% N x Grain Yield(kg ha^{-1})). Recovery of labeled N at the 56 kg cotton-applied N ha^{-1} rate following 280 kg corn-applied N ha^{-1} compared to 0 or 168 kg corn-applied N ha^{-1} decreased both years but only significantly in 2000 (Table 2.10). Addition of 112 kg cotton-applied N ha^{-1} significantly reduced recovery of labeled N following 168 and 280 kg corn-applied N ha^{-1} yet recovery of labeled N was highest following 0 corn-applied N.

The difference method was employed as a comparison as suggested by Jansson (1958) and in most instances overestimated recovery of applied N (Table 2.10). Although this method overestimated recovery, the overall trend of decreasing uptake efficiency following higher corn-applied N rates stayed the same. Fertilizer use efficiency was near or over 100% in several cases and is probably skewed because of the assumption that root growth and N uptake are similar in both unfertilized and fertilized plots. Similar recoveries for this soil were found by Boquet and Breitenbeck (2000) who attributed this apparent increased efficiency on increased root exploration of soil.

Table 2.10. Effect of residual and applied N on recovery of ^{15}N in above ground biomass of cotton cv. SG125 grown in rotation with corn, 1999-2000.

N Rate		1999	Recovery		2000	Recovery	
Corn	Cotton	Previous Corn Yield	Isotopic†	Difference‡	Previous Corn Yield	Isotopic	Difference
-----kg N ha^{-1}-----		-kg ha^{-1}-	-----------%-----------		-kg ha^{-1}	------------%-----------	
0	56	859	52.8 a§	99	1618	56.8 a	103
168	56	7514	48.8 ab	74	8055	58.6 a	101
280	56	8526	47.2 ab	91	7949	43.5 b	10
0	112	1141	51.2 a	82	2451	51.2 ab	89
168	112	7660	42.6 bc	71	7735	44.1 b	66
280	112	9005	39.8 c	54	8536	29.9 c	25

†Total ^{15}N recovered in plant tissue/total ^{15}N added to plot x 100.
‡Total N recovered in fertilized treatment – total N recovered in corresponding corn-applied N rate receiving 0 N / fertilizer N applied x 100 (Total N 168/56-Total N 168/0 / 56 x 100).
§Means within a column sharing the same letter do not differ significantly according to the least squares means test ($p \leq 0.05$).

In both years of the study, the majority of ^{15}N was recovered in seeds, increasing as a function of seedcotton yield increase. As corn-applied N increased, total ^{15}N found in seeds decreased. Increasing the rate of cotton-applied N applied to 112 kg N ha^{-1} increased the amount of ^{15}N accumulation in seeds, but not proportionally as the percentage of total ^{15}N recovered in seeds was similar for both cotton-applied N rates (Table 2.11).

Table 2.11. Effect of previous and applied N on N derived from fertilizer (Ndff) of cotton cv. SG 125 grown in rotation with corn as estimated by the isotopic method, 1999-2000.

	N Rate		Plant Component					
	Corn	Cotton	Seed	Branches	Burs	Leaves	Shed	Total
					Ndff†			
			--	kg ha^{-1}	--			
1999	0	56	14.6 f	3.8 ef	2.0 d	5.5	3.7 bc	29.6 de
2000	0	56	21.7 cd	3.6 f	2.1 d	4.0	0.3 e	31.8 d
Avg.‡			-------¶	-------	-------	4.8 b§	-------	-------
1999	168	56	13.8 f	3.1 f	1.9 d	5.1	3.5 cd	27.3 ef
2000	168	56	22.8 cd	3.5 f	2.2 d	3.9	0.3 e	32.8 d
Avg.			-------	-------	-------	4.5 b	-------	-------
1999	280	56	13.3 f	5.4 cd	2.1 d	2.7	2.9 d	26.4 ef
2000	280	56	15.8 ef	3.2 f	2.3 d	2.8	0.3 e	24.4 e
Avg.			-------	-------	-------	2.8 c	-------	-------
1999	0	112	31.2 b	9.0 a	4.8 ab	7.7	4.6 a	57.3 a
2000	0	112	40.4 a	6.3 bc	4.0 c	6.0	0.6 e	57.3 a
Avg.			-------	-------	-------	6.9 a	-------	-------
1999	168	112	24.8 c	7.0 b	4.8 ab	6.6	4.4 ab	47.7 bc
2000	168	112	33.3 b	5.1 d	4.1 bc	6.4	0.5 e	49.4 b
Avg.			-------	-------	-------	6.5 ab	-------	-------
1999	280	112	23.9 cd	5.6 cd	5.2 a	6.4	3.5 bc	44.6 c
2000	280	112	20.1 de	4.9 de	2.6 d	5.4	0.5 e	33.5 d
Avg.			-------	-------	-------	5.9 ab	-------	-------

†Nitrogen derived from fertilizer (Ndff). Ndff= Total N applied x %^{15}N recovered.
‡Means averaged across two years
§Averages within a column sharing the same letter do not differ according to the least squares means test ($p \leq 0.05$).
¶ A significant year X corn N X cotton N interaction occurred. Means sharing the same letter do not differ according to the least squares means test ($p \leq 0.05$).

Leaves and branches accounted for 12-15% of total ^{15}N recovered in both years. Although leaf N was not affected by residual N with 112 kg cotton-applied N ha^{-1}, total ^{15}N recovered in branches decreased with increasing previous corn-applied N. Burs accounted for 8-9% of total ^{15}N recovered and were largely unaffected by corn-applied N. Shed material accumulated 10% of total ^{15}N recovered in

1999 (due to the large amounts of abscised material) and less than 1% in 2000 (Table 2.11).

Table 2.12. Effect of previous and applied N on N derived from soil (Ndfs) of cotton cv. SG 125 grown in rotation with corn as estimated by the isotopic method, 1999-2000.

	N Rate		Plant Sample					
	Corn	Cotton	Seed	Branches	Burs Ndfs†	Leaves	Shed	Total
					kg ha^{-1}			
1999	0	56	57.9	16.7	6.2	26.3	12.5	119.6
2000	0	56	71.6	12.8	5.6	19.1	4.0	113.1
Avg.‡			64.8 b§	14.8 b	5.9 c	22.7 b	8.3 a	116.4 c
1999	168	56	61.1	15.0	6.8	26.1	11.4	120.4
2000	168	56	90.4	16.2	7.6	23.7	4.6	142.5
Avg.			75.8 b	15.6 b	7.2 c	24.9 b	8.0 a	131.5 b
1999	280	56	84.4	25.4	11.2	36.7	15.1	172.8
2000	280	56	98.9	18.5	12.0	29.8	5.3	164.5
Avg.			91.7 a	22.0 a	11.6 a	33.3 a	10.2 a	168.7 a
1999	0	112	62.7	18.8	7.4	28.7	10.7	128.3
2000	0	112	82.3	13.7	6.5	22.2	4.6 a	129.3
Avg.			72.5 b	16.3 b	7.0 c	25.5 b	7.7 a	128.8 bc
1999	168	112	67.3	17.2	9.0	32.4	11.8	137.7
2000	168	112	85.7	13.7	9.5 b	29.4	4.9	143.2
Avg.			76.5 b	15.5 b	9.3	30.9 ab	8.4 a	140.5 b
1999	280	112	78.7	23.3	14.7	33.2	14.4	164.3
2000	280	112	98.8	19.8	10.7	43.7	4.7	177.7
Avg.			88.8 ab	21.6 a	12.7 a	38.5 a	9.6 a	171.0 a

†Nitrogen derived from soil (Ndfs). Ndfs= Total N assimilated – Ndff..
‡Means averaged across two years
§Averages within a column sharing the same letter do not differ according to the least squares means test ($p \leq 0.05$).

The amount of total N derived from fertilizer (Ndff) decreased as corn-applied N rate increased especially in 2000 (Table 2.11). As corn-applied N rate increased and presumed residual N increased, a greater portion of the total N assimilated was derived from the soil (Ndfs)(Table 2.12). Although absolute values of Ndff increased with the 112 kg cotton-applied N ha^{-1} rate, a greater proportion of the total N was derived from the soil. Cotton grown following 280 kg corn-applied N ha^{-1} derived the most N from soil and derived only 30-40% of total N from fertilizer compared to 40-60% when following 0 or 168 kg N ha^{-1}. These results show the significant contribution of residual N especially when following corn receiving high rates of N.

Fertilizer use efficiency (FUE) is described as “the percentage recovery of fertilizer N by the crop” (Parr, 1973). It was decided that this term would be modified to describe N uptake efficiency (FUE). Fertilizer uptake efficiency was highest following 0 or 168 kg corn-applied N ha^{-1} for both the 56 and 112 kg cotton-applied N ha^{-1} rate (Table 2.10). Fertilizer uptake efficiency was generally greater at the 56 kg cotton-applied N ha^{-1} rate compared to the 112 kg cotton-applied N ha^{-1} rate, especially following corn-applied N. Addition of 112 kg cotton-applied N ha^{-1} reduced apparent efficiency when following 168 or 280 kg corn-applied N ha^{-1}. Although plant uptake of labeled N increased with the higher application, the proportional amount of labeled N recovered in the plant was less than with the lower rate, thus efficiency was decreased. Total N derived from soil was greatest for cotton following 280 kg corn-applied N ha^{-1} from the previous corn crop (Table 2.12.) This indicated that large amounts of cotton-applied N were not required to meet the N demands of the plant especially when following previous corn N rates of 280 kg N ha^{-1}. In fact, cotton uptake efficiency of 112 kg cotton-applied N ha^{-1} was significantly lower than 56 kg cotton-applied

N ha^{-1} although total N uptake and yields were similar, suggesting that addition of this much N was not necessary.

2.4 Discussion

In 1999, seedcotton yields were affected early in the season by increased residual N in that as corn-applied N rate together with increased cotton-applied N caused a temporal shift of seedcotton to the upper third of the plant. As a result, the plants became “top heavy” and lodged at the end of the season. However, this did not affect final yield due to dry conditions that led to efficient cotton harvest. Seedcotton in 2000 was much more evenly distributed among the three horizons and ultimately yielded better. Dry matter accumulation also reflected this as a greater percentage of assimilates and dry matter accumulated into vegetative tissue in 1999. Branches and leaves accounted for 30-44% and 18-26% of total dry matter in 1999 compared to 26-31% and 18-23% in 2000. It was also apparent that increased vegetative growth increased the potential for abscission of plant structures. The 1999 crop abscised considerably more material (10% of total dry matter) than the crop of 2000 (3% of total dry matter) presumably due to larger, more vegetative plants. Seed assimilated the majority of the total N in both years but less was assimilated into seed in 1999 (45-50%) compared to 2000 (55-60%).

Recovery of labeled N was also affected by corn-applied N rate. Recovery of applied N was greatest when cotton followed previous corn-applied N rates of 0 or 168 kg N ha^{-1}. Previous corn-applied N rates of 280 kg N ha^{-1} decreased the percentage of total N recovered for both applied rates but recovery was further decreased by the higher rate of 112 kg N ha^{-1}. In this case, although total ^{15}N recovered as well as Ndff values were higher with the 112 kg N ha^{-1} rate, percentage of fertilizer recovered vs. fertilizer applied was significantly decreased compared to 56 kg cotton-applied N ha^{-1}. This decrease in recovery suggested that application of 112 kg cotton-applied N ha^{-1} was excessive when following corn-applied N and efficient use of this amount of N by the plant did not occur. This apparent decrease in efficiency was substantiated by the fact that as corn-applied N rates increased to 280 kg N ha^{-1}, a greater portion of total N assimilated was derived from the soil. Contribution of applied N was apparent but the large amounts of applied N were not justified as total N assimilated as well as total dry matter production and yield were not significantly increased with addition of 112 kg N ha^{-1}.

A possible explanation for this decrease in recovery is the process of biological interchange. This is the process in which labeled N molecules are replaced with non-labeled molecules. An example would be that a labeled inorganic N molecule may be transformed into the organic phase via immobilization. It is for this reason that we also calculated the recoveries using the difference method. However this mechanism probably did not have a large effect since conditions favoring immobilization were not present and addition of fertilizer N tends to decrease immobilization and increase net mineralization (Jenkinson et al., 1985). Total Ndfs increased in plots receiving 168 or 280 kg corn-applied N ha^{-1} over those receiving 0 cotton-applied N with the addition of both 56 and 112 kg cotton-applied N ha^{-1}.

Regardless of the mechanism that affected labeled N recovery, the fact remained that N fertilizer uptake efficiency defined as ”the percentage recovery of fertilizer N by the crop” decreased as corn-applied N rates increased. Under these conditions, application of more than 56 kg N ha^{-1} to cotton following 168 or 280 kg corn-applied N did not usually result in increased yield and could possibly have been detrimental to both cotton yield and the environment. Uptake efficiency as well as regression of seedcotton yield versus cotton-applied N rate indicated no benefits to adding large amounts of N at planting (Fig. 2.3). Residual N provided adequate N to produce optimum yields with lower cotton-applied N rates. However, because fertilizer N uptake efficiency decreased at higher cotton-applied N rates and decreased efficiency leads to the potential for negative environment effects, benefits (both agronomically and economically) from increased N rate would not be realized.

CHAPTER 3

MANAGING COTTON N FERTILITY USING CRITICAL N CONCENTRATIONS COUPLED WITH FOLIAR APPLICATION OF UREA

3.1 Introduction

Nitrogen management is an important component in maximizing cotton yield in the Midsouth. Typically, throughout the Midsouth, N is applied before or near planting and often supplemented later in the growing season by side-dress treatments or foliar applications. This supplemental N is often applied to compensate for anticipated loss due to denitrification, leaching and immobilization. If favorable growing conditions are present and these anticipated losses do not occur, additional N may lead to over-fertilization, which could promote rank growth, delayed maturity and ultimately lost profits. Recently, problems such as groundwater contamination and hypoxic areas in the Gulf of Mexico have led to a general emphasis on reducing N inputs throughout the agricultural system (Gentry et al., 2000). Increased pressures from environmental groups and an increased emphasis on more efficient placement and use of fertilizers may require developing better management practices.

Previous research found that the fertilizer N requirement of clay soils is 30 to 40 percent greater than that of silt loam soils (Maples and Keogh, 1977). This increased need for N is often due to soil conditions that limit soil N uptake. Problems associated with clay soils often include waterlogging that could promote denitrification and reduced uptake, NH_4^+ binding to clay particles and reduced root efficiency due to soil cracking due to drought. These increased fertilizer N rates are aimed at optimizing yield under conditions that may be less than ideal for maximum N use efficiency.

Identifying plant N status during the year could lead to more efficient application of N and possibly less N application. Combinations of soil and plant tissue tests are often used to monitor cotton N status during the year to detect deficiencies as they occur. The petiole nitrate test has been the most popular method used to monitor plant N status during the growing season. However, because the test estimates flow of nitrate from the root to the leaf in the transpiration stream, the test is hypersensitive. This sensitivity often causes levels to vary with cultivar, growth stage, soil type, weather and insect damage, which make results difficult to interpret (Keisling et al., 1995; Heitholt, 1994; Sabbe and Zelinski, 1990; Maples et al., 1990). Leaf blade N tests are believed to be a direct measure of the plant's N status and provide an estimate of cumulative N uptake prior to sampling and the amount of reserve N. Like the petiole nitrate test, significant variations can occur with different cultivars, growth stage, soil type, weather and insect damage (Bell et al., 1997, 1998). Despite these caveats, results indicate that more accurate predictions of cotton nutritional status may be made using this method (Sabbe and Zelinski, 1990; Boquet et al. 1995; Boquet and Breitenbeck, 2000).

Foliar application of N is an alternative method of getting N to the plant. However, results from previous studies on the effects of foliar N applications have been inconsistent (Keisling et al., 1995; Smith et al., 1987; Anderson and Walmsley, 1984). Recent research indicates that yield response to foliar N applications is not always obtained (Bednarz, 1998). One explanation for this could be decreased uptake due to leaf age and the increased surface wax content (Bondada et al., 1997). Another reason that results have been erratic is that applications may occur when plants are N sufficient. Often, foliar applications are made at a predetermined growth stage (i.e., midbloom) regardless of deficiencies being absent or present. When plants N sufficient, a yield increase may not be observed over those treatments not receiving a foliar application. When this happens, researchers may conclude that application of foliar N provides no benefit. A means of avoiding this situation would be to couple foliar fertilization with tissue analyses. Although, many questions still exist regarding the use of leaf blade N tests along with foliar applications of N for cotton fertility management, the concept is promising and research is needed. Because of the possibility of environmentally regulated N use, as well as the relative inefficiency of cotton to remove N from clay soils, the use of foliar N along with minimal soil-applied N may be a viable alternative for cotton production. The objectives of this experiment were i) to determine whether minimal soil N along with foliar applications of N triggered by a leaf blade N test could be successfully used to manage N fertility of cotton grown on fine textured soils and ii) evaluate yield and fruiting characteristics that influence yield when grown under a variety of N management practices.

3.2 Materials and Methods

Cotton plots were established on 13 May 1999 and 12 May 2000. Seeds of cv. ‘STV 474’ (Stoneville Pedigreed Seed Company, Memphis, TN) were sown at rates to achieve a uniform plant population of approximately 100,000 plants ha^{-1} on a moderately drained Sharkey silty clay (very fine, montmorillonitic, non-acid, thermic, Vertic Haplaquepts). Each plot consisted of eight 1 m-wide rows 13.72 m long. In the first year of the study, a limited number of treatments were evaluated due to land availability. For the first year of the study, N treatments consisted of the current recommended rate applied near planting and as a 1:2 split treatment as well as two treatments that evaluated foliar applications (Table 3.1).

Table 3.1. Soil and foliar-applied N treatments applied to cv. STV 474 grown on Sharkey clay, 1999-2000.

Year	Preplant	Sidedress	Foliar
	-------------------------	kg N ha^{-1}	-------------------------
1999	0	0	0
	0	0	As Needed†
	44	0	As Needed
	44	90‡	0
	134	0	0
2000	0	0	0
	0	0	As Needed
	44	0	0
	44	0	As Needed
	44	90	0
	67	0	As Needed
	67	0	44§
	67	67 As Needed¶	0
	44	90	0
	134	0	0

†Foliar N (Urea 46% N) treatments were applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
‡Sidedress application was surface applied as NH_4NO_3 44 days after planting (DAP) in 1999 and 2000.
§Foliar urea application of 44 kg N ha^{-1} was applied in four consecutive 11 kg N ha^{-1} applications after triggered by a decline in leaf blade N concentration below the preset critical threshold.

¶Surface application of 67 kg N ha^{-1} was applied as NH_4NO_3 after triggered by a decline in leaf blade N concentration below the preset critical threshold.

An unfertilized treatment was included as a control. Additional space in 2000 allowed for additional treatments to test more hypotheses. In 2000, a soil-applied treatment that was triggered by leaf N concentration was added to determine if soil- or foliar-applied N was more efficient in correcting nutrient deficiencies (Table 3.1).

Fertilizer treatments as NH_4NO_3 were broadcast shortly after planting and were not incorporated. Split applications were applied 44 days after planting (DAP) in both years. With the exception of fertilization, all plots were maintained using standard production practices for dryland cotton production.

On a weekly basis, beginning at pin-head square, ten upper-most fully expanded leaves were removed from random plants from each plot for N analysis. The upper-most fully expanded leaf was generally the third or fourth leaf from the terminal bud (Maples et al., 1977). Because of the need for a fast turnaround, the samples were oven dried at 80^{o}C for 24 hr. in a forced air dryer. After drying, samples were ground using a Wiley Mill (Thomas Scientific Swedesboro, NJ) to pass a 0.5 mm screen. All grinding material was thoroughly cleaned between samples to prevent cross contamination. Ground leaf tissue was analyzed using a Leco FP-428 N analyzer (LECO, St. Joseph, MI) and total N concentration was determined (total-Kjeldahl- N equivalent)(Bell et al. 1997, 1998). According to Bell et al. (1997, 1998), critical N concentrations of 46, 40, 38 and 33 g N kg^{-1} dm were established as thresholds at pin-head square, early-bloom, mid-bloom and cut-out, respectively. A threshold curve was generated from these values to allow for treatment decisions throughout the season. As with insect control recommendations, these thresholds were interpolated and used to trigger supplemental foliar- and soil-applied N applications (Table 3.1). When N levels for individual plots fell below the interpolated critical value, supplemental foliar applications were made. Urea ($(NH_2)_2CO_2$) (46% N) was applied foliar at 5.6 kg N ha^{-1} as needed according to leaf blade N concentrations in 1999. In 2000, the dose was doubled (11.2 kg N ha^{-1}) in an effort to supply more N to meet the plant demand since no leaf burn was observed in 1999. Nitrogen was applied in an aqueous solution through 16 TX-6 hollow cone nozzles at a CO_2 pressure of 276 kPa to deliver a volume of 93.5 L ha^{-1} using a John Deere Hi-Cycle (Deere and Company Moline, IL).

All plants within two meters of row were selected at the end of the growing season for plant mapping. Plant mapping was conducted at two weeks after physiological cutout to determine first fruiting node, total reproductive nodes, percentage square set and boll number. After defoliation, the two meters of row used for plant mapping was cut and removed from the field. Plant samples were hand harvested and yield components were evaluated both temporally and spatially using box mapping procedures (Jenkins and McCarty, 1995). Bolls were pooled by position into each of the following horizons: Horizon 1 (mainstem nodes (MSN) 4-8), Horizon 2 (MSN 9-12) and Horizon 3 (MSN 13+), counted and seedcotton weighed. Seedcotton yield was determined from the center four rows of each plot using a mechanized picker modified for small plots. Each plot was end trimmed 1.5 m to eliminate end of the row effect.

Four replications of five fertilizer treatments were used in the first year and five additional treatments were added in the second year (Table 3.2). Treatments were arranged in a randomized complete block. Data were analyzed using analysis of variance procedures (PROC GLM) (SAS, 2000). Means were separated using Fisher's Protected LSD (p=0.05).

3.3 Results

Rainfall distribution for the two years of the study was not similar and yields and N concentrations reflected these differences (Table 3.1). Because additional treatments were added in 2000 and data were not pooled, data are presented by year and comparisons between years are made where applicable.

Table 3.2. Rainfall and average air temperature data for Northeast Research Station, St. Joseph, LA, during 1999 and 2000 growing seasons and 70 year averages.

	Rainfall			Air Temperature		
	1999	2000	70 Year Average	1999	2000	70 Year Average
	------------------cm month^{-1}-------------			---------------------^{o}C------------------		
April	6.7	19.5	12.5	22	18	19
May	7.2	5.4	12.4	24	26	23
June	9.3	7.0	9.3	28	27	27
July	3.5	4.5	10.8	29	29	28
August	11.6	5.5	8.2	29	29	28
September	7.3	6.6	6.8	24	26	24

3.3.1 Leaf Blade N Concentration

3.3.1.1 1999

Leaf blade N concentrations throughout the growing season varied depending on N rate, crop stage and soil moisture content. Leaf blade N concentrations fell well below the threshold critical values in all fertilizer treatments early in the season (37 DAP) due to unusually dry conditions (Figure 3.1). However, before the onset of dry weather, the 0 + foliar as needed treatment (FAN) required applications of foliar N beginning at pin-head square (30 DAP). Application of foliar N failed to bring leaf N concentrations above the critical value for that treatment when sampled the following week and concentrations stayed below threshold for most of the season. Sampling results at 37 DAP reflected the drought-like conditions and suggested reduced N uptake as all treatments showed signs of deficiency. Effective rainfall occurred before the next sampling date and leaf blade N concentrations for all treatments rose above threshold. As the season progressed and blooming began (58 DAP), treatments receiving less than the recommended N rate of 134 kg N ha^{-1} had leaf N concentrations fall below the critical value. Subsequent foliar applications of 5.6 kg N ha^{-1} throughout the growing season were unable to bring leaf blade N levels above those considered critical (Figure 3.1). Leaf blade N concentrations of plants receiving soil-applied N rates of 44 kg N ha^{-1} did not fall below the critical value until the onset of blooming (58 DAP. Subsequently, foliar applications of urea were necessary in all FAN plots. Those plots receiving a pre-plant application of 44 kg N ha^{-1} plus FAN responded initially by rising above the threshold but, as the sink strength (boll load) became stronger, leaf blade N levels began to decline (Figure 3.1).

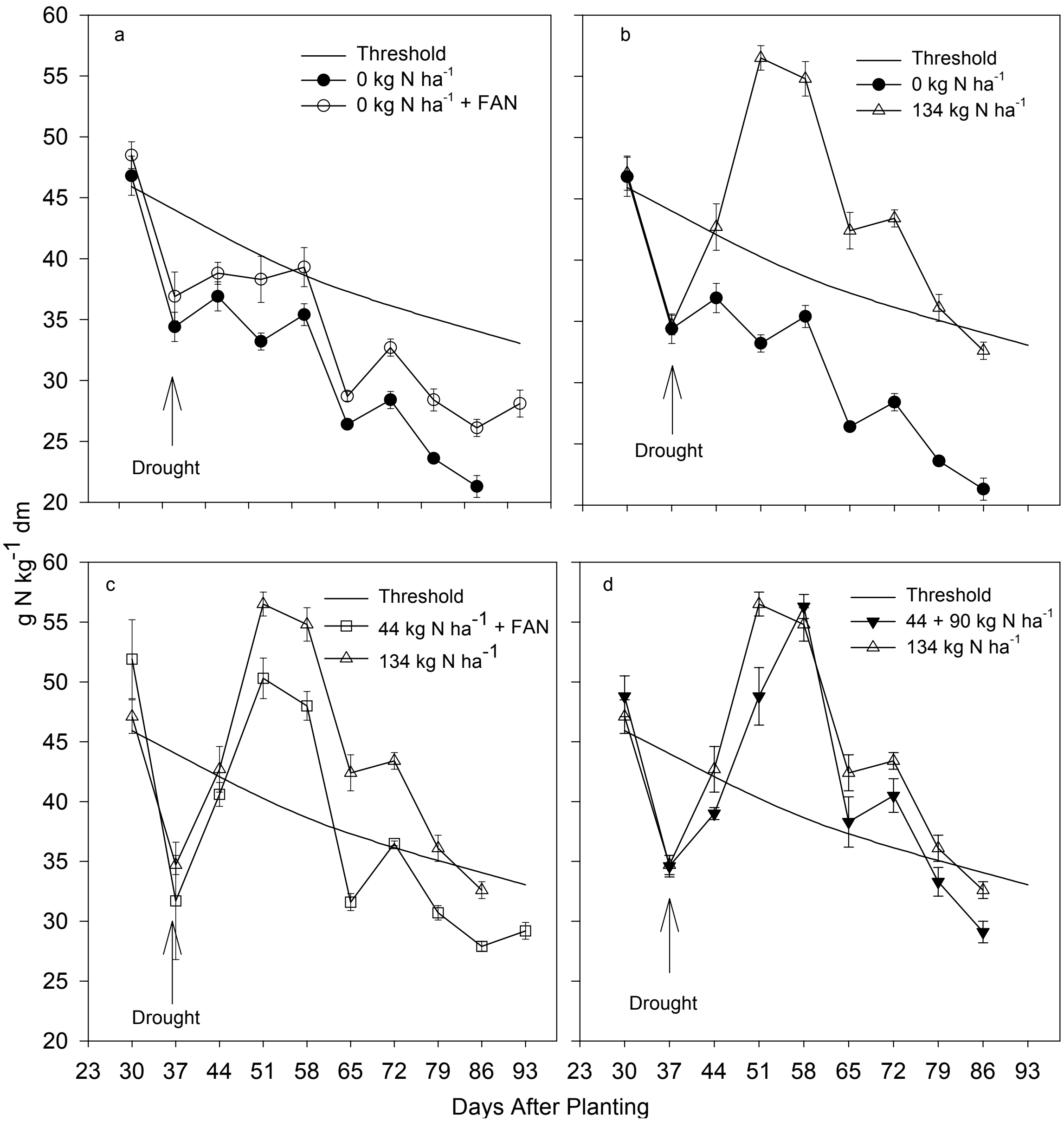

Figure 3.1. Comparison of leaf blade N concentrations of selected N treatment combinations of cv. STV 474 grown on Sharkey Clay, 1999. Error Bars represent ± SE. FAN= Foliar N (Urea 46% N) treatments were applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.

At 58 DAP, the 44 kg N ha^{-1} plus FAN had an average leaf N concentration of about 13% lower than the 134 kg N ha^{-1} treatment. At that time, the 44 kg N ha^{-1} treatments had received an average of two foliar applications of 5.6 kg N ha^{-1} each. By the third week of bloom (72 DAP), plots receiving 44 kg N ha^{-1} plus supplemental foliar N applications still had an average leaf blade N concentration 13% less than the 134 kg N ha^{-1} treatment and had received an average of 16.8 kg N ha^{-1} foliar-applied N.

On average, plots receiving 0 and 44 kg N ha^{-1} at pre-plant required 36 kg N ha^{-1} and 28 kg N ha^{-1} as foliar-applied urea, respectively beginning at 37 DAP and continuing until 79 DAP. Because maximum N assimilation occurs during boll set (51-72 DAP) and bolls are the major N sinks, a significant reduction in N transport to mainstem vegetative development occurred as evidenced by declining N concentration in the uppermost fully expanded leaf. Plots receiving minimal soil N were unable to maintain sufficiency during this period despite foliar applications. On the other hand, because of high leaf N concentrations before blooming and adequate reserve N in the soil, the 134 kg N ha^{-1} treatment was able to maintain sufficiency.

3.3.1.2 2000

Cotton in 2000 did not experience early season drought conditions after planting as in 1999. Although rainfall was below average, rainfall occurred at critical periods throughout the season. Contrary to 1999, leaf N values were above those considered critical during the first two weeks of sampling. At 44 DAP, the 0 + FAN required application of N. Application of N generally continued on a weekly basis until 72 DAP when plants began to reach cutout. Leaf blade N concentration in plots receiving 44 kg N ha^{-1} did not drop below the critical level until 51 DAP as plants were nearing the bloom stage. An average of 39.2 kg foliar N ha^{-1} was applied for plots receiving 0 N at planting. Addition of 44 kg N ha^{-1} at planting decreased the need for foliar applications to an average of 22.4 kg N ha^{-1} applied foliar. These values are similar to those reported in 1999 where plots needed an average of 36.4 and 28 kg foliar N ha^{-1} following 0 and 44 kg N ha^{-1} at planting, respectively. Plots receiving 67 kg N ha^{-1} at planting did not show any deficiencies until 58 DAP and blooming began. These plots only required an average of 11.2 kg N ha^{-1} foliar-applied but yields did not reflect this apparent sufficiency. The 67 kg N ha^{-1} as-needed sidedress treatment had variable results. Nitrogen concentrations fell below the threshold at 51, 65 and 72 DAP for this treatment depending on location in the field. Applications of sidedress N brought N concentrations above the critical level but failed to produce optimum yield. Soil application of N late in the season was unable to be utilized by the plant presumably due to less than optimum soil moisture at the time of application. As in 1999, plots receiving the optimum soil-applied rate of 134 kg N ha^{-1} either all at once at planting or in a split application, did not become deficient at any time during the season. During the time of maximum N assimilation (51-72 DAP), plots receiving 134 kg N ha^{-1} at planting had leaf N concentrations of 15, 7, 12 and 5% greater than the critical level at 51, 58, 65 and 72 DAP, respectively. These values were at least 9% higher than plots receiving 44 kg N plus FAN for all sampling dates except 65 DAP. The increase

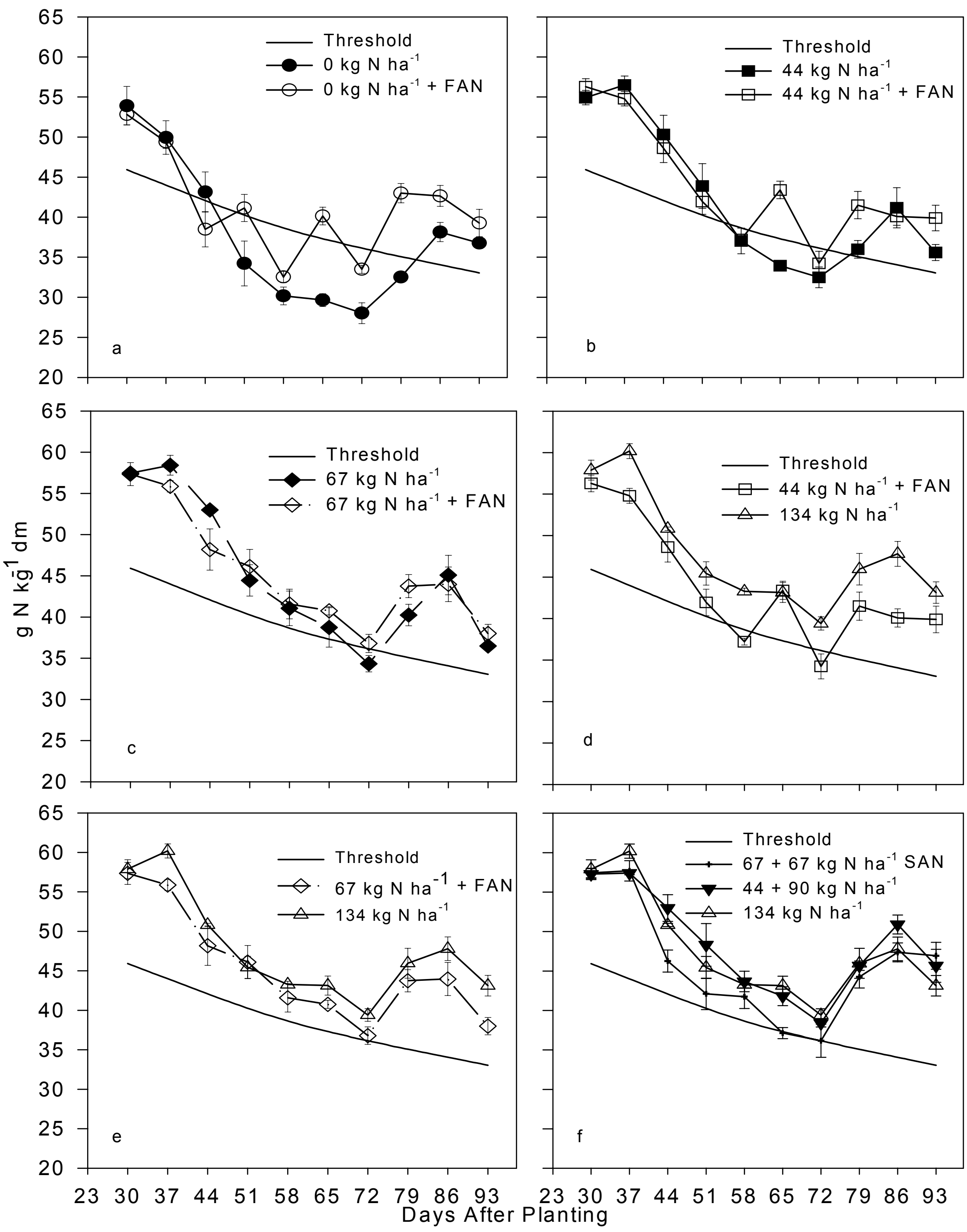

Figure 3.2. Comparison of leaf blade N concentrations of selected N treatment combinations of cv. STV 474 grown on Sharkey Clay, 2000. Error Bars represent ± SE. FAN= Foliar N (Urea 46% N) treatments were applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold. SAN= Surface application of 67 kg N ha^{-1} was surface applied as needed as NH_4NO_3 after being triggered by a decline in leaf blade N concentration below the critical threshold.

in leaf blade N at 65 DAP in the 44 + FAN treatment was due to a foliar application at 58 DAP. However, leaf N dropped dramatically by the next sampling date. Due to a higher dose, applications of foliar N did a better job reversing declines in leaf N concentration in 2000 than in 1999 but the correction was still temporary and yields were not optimum.

Although addition of foliar N spiked N concentrations in leaves after application, foliar applications of N were unable to maintain leaf N concentrations above those considered critical for optimum yield for more than a short period of time. This outcome apparently had an effect on yield. Although leaf N concentrations stayed above critical levels for much of the growing season for plots receiving 67 kg N ha^{-1} at planting, values were generally only 5% below those of the recommended rate, yet, yields were well below optimum. Because of only slight differences in leaf N concentrations and the relatively large differences in yield, leaf blade critical values used in this study were considered to be too low for the period of boll fill (51-72 DAP).

3.3.2 Seedcotton Yield

Seedcotton yield response by treatments reflected the leaf blade N results (Table 3.3). Plots receiving 0 N for the year yielded an average of 1307 kg ha^{-1}. Applications of FAN to plots receiving 0 soil-applied N resulted in a 31% increase in yield over plots receiving 0 N (Table 3.3). Addition of 44 kg ha^{-1} at planting along with FAN, yielded an average of 1117 kg ha^{-1} more than untreated check and 528 kg ha^{-1} more than the 0 + FAN. However, this N treatment yielded 20% less than the recommended treatment of 134 kg N ha^{-1} applied all at once at planting but only yielded 11% less than the recommended N rate applied as a split. This discrepancy was primarily due to dry conditions that occurred after the

Table 3.3. Effect of N treatment on seedcotton yields of cv. STV 474 grown on Sharkey clay, 1999 and 2000.

Preplant N	Sidedress N	Foliar N	Foliar N Applied	1999	Foliar N Applied	2000	2 Year Average
				----kg ha^{-1}----			
0	0	0	0	1307 d†	0	1138 d	1222 d
0	0	As Needed‡	36	1896 c	39	1939 c	1917 c
44	0	0	-------	-------	0	1953 c	-------
44	0	As Needed	28	2424 b	22	2433 b	2428 b
67	0	0	-------	-------	0	2335 b	-------
67	0	As Needed	-------	-------	11	2528 b	-------
67	0	44§	-------	-------	11#	2535 b	-------
67	67 As Needed¶	0	-------	-------	0	2534 b	-------
44	90	0	0	2736 ab	0	3076 a	2906 a
134	0	0	0	3007 a	0	3198 a	3103 a

† Means within a column sharing the same letter do not differ significantly according to Fisher's Protected LSD ($p \leq 0.05$).
‡ Foliar N (Urea 46% N) treatments were applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
§ Foliar urea application of 44 kg N ha^{-1} was applied in four consecutive 11 kg N ha^{-1} applications after triggered by a decline in leaf blade N concentration below the preset critical threshold.
¶ Sidedress application of 67 kg N ha^{-1} was surface applied as NH_4NO_3 after triggered by a decline in leaf blade N concentration below the preset critical threshold.
# Average of four replications. Only one rep within the treatment received all four applications.

split application was applied which did not allow for the plants to fully utilize the applied N. Plots receiving 44 kg N ha^{-1} + FAN appeared to have a similar cosmetic appearance as plots receiving the recommended rate of 134 kg N ha^{-1}

throughout much of the season but recommended N rates provided a significant yield advantage (Table 3.3).

Yields were generally slightly better in 2000 compared to 1999. Unfertilized plots yielded an average of only 1138 kg seedcotton ha^{-1} (Table 3.3). Addition of FAN to plots receiving 0 preplant N increased seedcotton yields 801 kg ha^{-1} over the unfertilized control. Application of foliar N to plots receiving 44 kg N ha^{-1} at planting increased yield 480 kg ha^{-1} over those receiving only 44 kg ha^{-1}. Combinations of 67 kg N ha^{-1} with 0, FAN or soil applied sidedress N as needed were all statistically equivalent and averaged 2483 kg seedcotton ha^{-1}, regardless of N combination (Table 3.3). No benefit was observed by addition of foliar- or soil-applied N as needed to this amount of preplant N. Although, plots receiving 67 kg N ha^{-1} at planting had N sufficient leaf blade concentrations throughout the year and foliar application was rarely needed based on the threshold values used, yields were 25% below those obtained with the recommended rate of 134 kg N ha^{-1}. As in 1999, the 134 kg N ha^{-1} treatment, either all at once at planting or split, had the highest yield and outperformed all treatments receiving foliar N applications (Table 3.3). Plots receiving 44 or 67 kg N ha^{-1} at planting plus FAN, yielded an average of 24 and 20% less seedcotton than the 134 kg N ha^{-1} rate, respectively. The recommended N treatment of 134 kg N ha^{-1} at planting yielded significantly higher than treatments utilizing foliar N in both years of the study. Although benefits of foliar N were observed in plots receiving minimal soil-applied N, foliar applications did not approach yields of the recommended soil-applied treatment.

3.3.3 Yield Partitioning

3.3.3.1 1999

First position bolls contributed to the majority of seedcotton. Approximately 75% of total yield was accounted for by first position fruit across all sympodial branches for all fertilizer treatments. As fertilizer rate increased, a greater portion of the seedcotton was found on the upper sympodia of the plant. For example, 20, 51 and 8% of total yield was found on first position fruit in the first horizon (Mainstem nodes (MSN)<8), second horizon (MSN 9-12) and third horizon (MSN >12), respectively in the unfertilized plots. By contrast, plots receiving 134 kg N ha^{-1} contained 7, 37 and 20% of total yield on first position fruit in horizons 1, 2 and 3, respectively (Table 3.4). Total boll number and seedcotton weight also increased with addition of fertilizer.

Because plants were cosmetically similar at first bloom, it was thought that yield of plots receiving 44 kg N ha^{-1} at planting supplemented by FAN might be comparable to that of plots receiving the optimum rate of N. Temporal distribution of seedcotton yield was similar for both fertilizer treatments in that most yield was found on the first position in the second horizon (Table 3.4, 3.5). Recommended fertilizer rates of 134 kg N ha^{-1} increased position two seedcotton in the second horizon and position one seedcotton in the third horizon, 72 and 40%, respectively over the plots that received 44 kg N ha^{-1} + FAN, although each accounted for roughly 40 and 15% of total yield for the two treatments, respectively (Table 3.4).

Table 3.4. Effect of N treatment on temporal and spatial distribution of seedcotton yield of cv. STV 474 grown on Sharkey clay, 1999.

		Horizon 1†			Horizon2			Horizon3			
N Rate	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
kg ha^{-1}	g m^{-2}										
0-0-0§	28.8	38.1	3.3	0.0	96.0	5.5	0.0	15.3	0.0	0.0	187.1
0-0-FAN¶	31.0	36.6	5.5	1.0	103.4	14.9	0.0	27.5	0.8	0.0	220.8
44-0-FAN	55.4	38.7	6.1	1.2	135.8	12.4	0.0	46.7	1.0	0.0	297.3
44-90-0	68.3	53.1	13.6	4.6	147.5	21.2	0.0	42.5	7.7	0.0	358.5
134-0-0	76.8	28.0	7.7	1.0	147.9	43.7	2.9	78.2	8.3	0.0	394.6
LSD (0.05)	28.7	NS#	NS	NS	26.4	12.7	NS	27.1	NS	NS	52.8

† Horizon 1=(Mainstem Nodes (MSN)<9, Horizon 2=MSN 9-12, Horizon 3=MSN>12.
‡Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Denotes Preplant N--Sidedress N--Foliar N application, respectively.
¶ FAN denotes Foliar N As Needed as urea (46% N) applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
# NS=Non-significant ($p \leq 0.05$).

The increase in yield of cotton receiving 134 kg N ha^{-1} at planting was somewhat correlated to an increase in the number of second position bolls found in the second horizon (r=0.51) but highly correlated to first position bolls found in the third horizon (r=0.71). This increase in boll number resulted in an overall increase in the seedcotton weight in these temporal and spatial regions of the plant although the amount of seedcotton per boll was not as highly correlated to yield as boll number (r=0.22 vs. r=0.62). Plants receiving 44 kg N ha^{-1} + FAN had similar weights per boll in all horizons. Second and third position fruit across all sympodia made up less than 7% of total yield in plots receiving 44 kg N at planting along with FAN. However, second and third position fruit comprised 16% of total yield in plots receiving 134 kg N ha^{-1} at planting. Increased first position seedcotton weight in the second and third horizons along with increased numbers of second and third position fruit led to the 583 kg ha^{-1} increase in seedcotton yield at harvest for the 134 kg N ha^{-1} rate.

Table 3.5. Effect of N treatment on temporal and spatial distribution of boll numbers of cv. STV 474 grown on Sharkey clay, 1999.

		Horizon 1†			Horizon 2			Horizon 3			
N Rate	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
kg ha^{-1}	-----------------	-----------------	-----------------	-----------------	-----boll m^{-2}-----	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------
0-0-0§	9.0	10.0	1.0	0.0	25.3	2.0	0.0	4.0	0.0	0.0	51.3
0-0-FAN¶	9.0	9.0	1.2	0.2	25.3	4.0	0.0	7.8	0.2	0.0	56.8
44-0-FAN	17.8	9.2	1.2	0.2	30.5	3.0	0.0	11.5	0.2	0.0	73.8
44-90-0	13.3	11.5	3.3	1.0	31.8	5.0	0.0	10.5	2.3	0.0	78.5
134-0-0	16.8	6.5	1.8	0.2	31.3	9.7	0.7	18.0	2.5	0.0	87.5
LSD (0.05)	NS#	NS	NS	NS	5.6	8.4	NS	6.6	NS	NS	13.1

† Horizon 1=Mainstem Nodes (MSN)<9, Horizon 2=MSN 9-12, Horizon 3=MSN>12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Denotes Preplant N--Sidedress N--Foliar N application, respectively.
¶ FAN denotes Foliar N As Needed as urea (46% N) applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
# NS=Non-significant (p≤0.05).

The data indicate that first position fruit in the first and second horizons are not as affected by pre-plant applications as are fruit set later in the growing season. Although not significant, higher N rates early in the season appeared to reduce early fruiting in lower horizons (Table 3.4). However, a higher rate of fertilizer more than made up for the lack of lower fruit later in the season (horizon 2-3), which ultimately translated into higher crop yields (Table 3.2).

The MSN location of the first sympodial fruiting branch was not affected by fertilizer treatment. However, cotton plots receiving 134 kg N ha^{-1} at planting were an average of 10 cm taller than cotton in plots receiving 44 kg N at planting supplemented by foliar N (Table 3.6).

Table 3.6. Effect of N treatment on first fruiting node, total sympodial branches and plant height at harvest for cv. STV 474 grown on Sharkey clay, 1999.

Preplant N	Sidedress N	Foliar N	First Fruiting Branch†	Total Sympodial Branches‡	Plant Height at Harvest§
-----------------kg ha^{-1}-----------------			mainstem -----node----	---no. $plant^{-1}$---	------cm------
0	0	0	8.0	7.4	70.6
0	0	As Needed‡	8.2	8.5	80.8
44	0	As Needed	7.9	9.6	89.1
44	90	0	8.1	10.6	94.9
134	0	0	8.6	10.7	100.6
		LSD (0.05)	NS§	0.6	2.9

†First sympodial branch with a potential fruiting site.
‡ Foliar N As Needed as urea (46% N) applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
§ NS=Non-significant ($p \leq 0.05$).

Taller plants with the recommended treatment and an average of at least one more fruiting node per plant (Table 3.6) could possibly explain the increase in fruit. The difference between optimum treatments and FAN treatments resulted from 1 more 2nd position boll in Horizon 2 and 1 more 1st position boll in Horizon 3.

3.3.3.2 2000

As in 1999, the majority of yield in unfertilized plots was found on the lower portion of the plant. Seedcotton from first position bolls made up 86% of total yield with 80% coming from fruiting branches below MSN 13. Second and third position fruit contributed less than 2% of total yield. Vegetative bolls provided the remainder of total yield (12%). Addition of foliar N to these plots increased total seedcotton produced but distribution was similar to that of the control with 80% of total yield coming from first position bolls. First position bolls from MSN <12 horizons provided 72% of total yield. Second and third positions contribute only 10% to the total with vegetative bolls making up the balance. (Table 3.7). Addition of 44 kg N ha^{-1} increased total seedcotton yield by 815 kg ha^{-1} over the control. Although, both treatments had similar numbers of first position bolls from sympodia of MSN <8 and similar seedcotton weights in this temporal region, addition of 44 kg preplant N significantly increased second position bolls and seedcotton weight there. However, the majority of the increase in yield in this treatment was achieved by an increase in first position bolls and seedcotton in horizon 2 (Table 3.7, 3.8). Foliar N as needed increased total seedcotton 1295 and 480 kg ha^{-1} over the control and 44 kg N preplant treatments, respectively. Distribution of seedcotton in this treatment was somewhat different than both the control and 44 kg N ha^{-1} without FAN. Although, 65% of seedcotton yield came from first position fruit on MSN <12, second and third position fruit on all sympodia contributed to 18% of total yield compared to <2% and 10% of total yield in the control and 44 kg N without FAN, respectively. Increase in seedcotton due to foliar application was primarily due to

Table 3.7. Effect of N treatment on temporal and spatial distribution of seedcotton of cv. STV 474 grown on Sharkey clay, 2000.

		Horizon 1†			Horizon 2			Horizon 3			
N Rate	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
--kg ha^{-1}--	--g m^{-2}--										
0-0-0§	14.8	63.4	0.4	0.0	36.9	0.5	0.0	6.6	1.2	0.0	123.5
0-0-FAN¶	21.1	85.2	15.7	0.4	75.7	5.1	0.5	19.9	1.2	0.2	224.6
44-0-0	18.5	78.5	11.4	0.0	94.2	11.3	1.4	16.5	3.6	0.0	235.1
44-0-FAN	19.0	89.3	18.3	1.8	76.7	17.8	1.3	27.5	5.8	0.4	257.8
67-0-0	19.4	68.4	13.8	1.1	92.7	17.4	2.9	29.2	5.9	1.2	251.9
67-0-FAN	21.2	90.7	22.3	1.6	81.3	18.5	2.2	29.8	4.5	0.0	272.0
67-0-44	35.8	82.7	25.3	3.9	112.9	24.6	5.6	42.4	8.6	0.9	342.5
67-67#-0	32.0	70.3	19.6	1.5	96.0	18.3	2.0	54.8	6.4	0.4	301.1
44-90-0	27.1	92.7	28.5	2.3	97.1	27.9	7.3	59.8	16.1	2.6	361.2
134-0-0	32.6	91.1	32.9	4.2	102.2	30.1	4.2	57.7	11.8	0.9	367.4
LSD (0.05)	NS††	NS	10.9	NS	28.9	13.3	NS	19.2	7.8	1.1	57.4

† Horizon 1=Mainstem Nodes (MSN)<9, Horizon 2=MSN 9-12, Horizon 3=MSN>12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Denotes Preplant N--Sidedress N--Foliar N application, respectively.
¶ FAN denotes Foliar N As Needed as urea (46% N) applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
# Surface application of 67 kg N ha^{-1} was applied as NH_4NO_3 after triggered by a decline in leaf blade N concentration below the preset critical threshold
††NS=Non-significant ($p \leq 0.05$).

increased first and second position boll number and seedcotton weight in the third horizon. Plots receiving 67 kg N ha^{-1} at planting, with or without additional N from foliar or soil applications, did not yield significantly higher than plots receiving 44 kg N ha^{-1} at planting along with FAN. Yield distribution was similar for all combinations of 67 kg N ha^{-1} with the majority of yield coming from sympodia off MSN <12. Maximum yields were obtained by addition of 134 kg N ha^{-1} applied at planting. Yield was evenly distributed among fruiting branches along the mainstem. Plots receiving 134 kg N ha^{-1} at planting had significantly more first position bolls on upper sympodia (>12) than plots receiving 44 or 67 kg N ha^{-1} plus FAN. Significantly more second position bolls in the second horizon were also found in plots receiving 134 kg N at planting than those receiving 44 kg N at planting plus FAN. The real difference in number of bolls and seedcotton weight could be found on sympodia >MSN 12. Plots receiving 134 kg N ha^{-1} at planting had significantly more first and second position bolls in this temporal region than all treatments receiving FAN. This increase in boll number contributed to a significant increase in seedcotton weight in this region. As in 1999, the yield advantage of the 134 kg ha^{-1} preplant N treatment could be found in the upper portions of the plant (r=0.73) and on fruiting positions greater than one (r=0.79).

First fruiting node was not significantly affected by N rate in 2000 but as fertilizer N increased, both plant height and the number of total fruiting nodes increased (Table 3.9). Increasing total height and total sympodial node production allowed for both increased canopy and more potential fruiting sites.

Again, maturing 1-2 more bolls per plant would be all that is needed to produce maximum yields.

Table 3.8. Effect of N treatment on temporal and spatial distribution of boll numbers of cv. STV 474 grown on Sharkey clay, 2000.

		Horizon 1†			Horizon 2			Horizon 3			
N Rate	Veg	Pos 1‡	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
--kg ha^{-1}--	boll m^{-2}										
0-0-0§	4.8	17.2	0.2	0.0	10.4	0.3	0.0	3.0	0.4	0.0	36.0
0-0-FAN¶	6.5	18.8	3.9	0.2	19.0	1.8	0.3	7.3	0.5	0.2	58.2
44-0-0	4.7	18.5	3.3	0.0	22.4	3.3	0.5	4.8	1.2	0.0	58.4
44-0-FAN	4.9	20.4	4.2	0.4	20.2	5.2	0.4	8.4	1.4	0.2	65.3
67-0-0	5.0	16.2	3.9	0.4	22.7	4.9	0.8	9.2	2.4	0.4	65.5
67-0-FAN	4.9	21.0	6.0	0.7	20.5	5.3	0.8	9.0	1.5	0.0	69.5
67-0-44	9.8	20.0	6.0	1.0	26.8	6.2	1.5	13.2	2.7	0.4	87.3
67-67#-0	8.8	16.9	5.3	0.4	23.8	5.0	0.5	16.8	2.3	0.2	79.7
44-90-0	6.5	20.3	7.3	0.7	22.9	6.9	1.9	16.4	4.9	0.9	88.4
134-0-0	8.3	20.7	7.7	1.0	22.4	7.0	1.3	16.5	3.8	0.3	88.7
LSD (0.05)	NS††	NS	2.4	NS	5.9	3.4	NS	5.2	2.2	0.4	13.3

† Horizon 1=Mainstem Nodes (MSN)<9, Horizon 2=MSN 9-12, Horizon 3=MSN>12.
‡ Denotes first, second and third and beyond fruiting sites on a sympodial branch.
§ Denotes Preplant N--Sidedress N--Foliar N application, respectively.
¶ FAN denotes Foliar N As Needed as urea (46% N) applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
# Surface application of 67 kg N ha^{-1} was applied as NH_4NO_3 after triggered by a decline in leaf blade N concentration below the preset critical threshold.
††NS=Non-significant ($p \leq 0.05$).

Table 3.9. Effect of N treatment on first fruiting node, total number of sympodial branches and plant height at harvest of cv. STV 474 grown on Sharkey clay, 2000.

Preplant N	Sidedress N	Foliar N	First Fruiting Node†	Total Sympodial Branches	Plant Height at Harvest
----------------kg N ha^{-1}----------------			Maninstem ----node----	--no. $plant^{-1}$--	------cm-----
0	0	0	7.1	9.5	60.3
0	0	As Needed‡	6.8	10.8	66.9
45	0	0	6.8	10.6	68.6
45	0	As Needed	6.5	11.2	69.6
67	0	0	6.9	12.0	70.8
67	0	As Needed#	6.8	12.2	75.1
67	0	44	6.8	12.0	76.5
67	67§	0	7.0	12.3	73.9
44	90	0	6.6	12.8	79.6
134	0	0	6.8	12.2	80.5
		LSD (0.05)	NS¶	1.0	3.8

†First sympodial branch with a potential fruiting site.
‡ Foliar N As Needed as urea (46% N) applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
§ Surface application of 67 kg N ha^{-1} was applied as NH_4NO_3 after triggered by a decline in leaf blade N concentration below the preset critical threshold.
¶ NS=Non-significant ($p \leq 0.05$).

3.3.4 Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) is described (NUE=seedcotton yield / kg N applied). A maximum NUE was achieved in both years in cotton receiving 0 N at planting and supplemented with FAN (Table 3.10). Although use efficiency of cotton receiving less than optimal soil-applied N and FAN was less than those receiving 0 N + FAN, yields were significantly greater in both years. Cotton fertilized with the recommended N rate had the highest yields but the lowest NUE. Although NUE of cotton receiving less than optimal N at planting + FAN yielded 22% less than cotton receiving the recommended N rate, NUE was 34% greater (Table 3.10). Although NUE generally declines as yields increase, applications of foliar N at the correct time could increase yield and still remain more efficient than the recommended soil applied rate.

Table 3.10. Effect of N treatment on N use efficiency (NUE) of cv. STV 474 grown on Sharkey clay, 1999 and 2000.

Preplant N	Sidedress N	Foliar N	1999	2000	2 Year Average
				NUE	
---------------kg ha^{-1}------------------			-------kg seedcotton kg^{-1} N-----		
0	0	As Needed‡	51.98 a	50.18 a	51.08 a
44	0	0	-------	44.39 b	-------
44	0	As Needed	33.58 b	36.43 c	35.01 b
67	0	0	-------	34.85 c	-------
67	0	As Needed	-------	33.72 c	-------
67	0	44§	-------	33.35 c	-------
67	67 As Needed¶	0	-------	18.92 d	-------
44	90	0	20.43 c	22.96 d	21.70 c
134	0	0	22.40 c	23.87 d	23.14 c

† Means within a column sharing the same letter do not differ significantly according to Fisher's Protected LSD (p≤0.05).
‡ Foliar N (Urea 46% N) treatments were applied to individual plots within treatments as needed when leaf N concentrations fell below critical threshold.
§ Foliar urea application of 44 kg N ha^{-1} was applied in four consecutive 11 kg N ha^{-1} applications after triggered by a decline in leaf blade N concentration below the preset critical threshold.
¶ Sidedress application of 67 kg N ha^{-1} was surface applied as NH_4NO_3 after triggered by a decline in leaf blade N concentration below the preset critical threshold.

3.4 Discussion

Maximizing seedcotton yield was not successful using minimal soil N along with FAN. Previous studies in Louisiana have shown that daily N assimilation rates were generally low until pin-head square (0.18-0.29 kg N ha^{-1} d^{-1}). Daily N assimilation increased once fruiting began with rates of 1.5 kg N ha^{-1} d^{-1} until about 48 DAP. Maximum daily assimilation occurred between 49 and 71 DAP with rates of 3.0 kg N ha^{-1} d^{-1} (Boquet and Breitenbeck, 2000). Assuming that these rates are similar for cotton grown on Sharkey clay, N assimilation exhausted the applied N supply of cotton receiving minimal soil applied N before blooming began. Cotton grown with minimal fertilizer N relied primarily on remobilized N to satisfy boll fill sink demand (Oosterhuis et al., 1983). As N was remoblilized, leaf N concentration dropped and subsequent FAN treatments could not supply adequate N to meet the crop demands. As a result, the plant was unable to support bolls on the outer portions of sympodial branches and upper mainstem branches. Reevaluation of critical values suggested that values should be increased (P.F. Bell, personal communication). Leaf N concentrations of 43 g N kg^{-1} prior to early bloom would have triggered applications of N sooner. Application of foliar N earlier in the season may have possibly maintained leaf N concentrations above critical levels during boll fill. Triggering applications earlier may have resulted in multiple applications of foliar N that may have maintained leaf N concentrations above critical levels as sink demand increased resulting in optimum seedcotton yield. Also, application of a preset amount of total N applied when leaf N concentrations dropped below a critical value and continued until the preset amount was applied may have resulted in increased yield. Applications of 67 kg N ha^{-1} at planting along with an additional 44 kg N ha^{-1} FAN may have maintained leaf N concentrations sufficient for optimum yields. However, leaf N concentrations in plots receiving 67 kg N ha^{-1} at planting rarely dropped below critical thresholds used in this study. Although the test suggested sufficiency, yields were less than optimum. Although foliar applications did not result in maximum yields, yields were only 20% less than the recommended treatment. However, N use efficiency (NUE=seedcotton yield / kg N applied) of foliar-applied rates was 34% greater than the recommended treatment for treatments receiving foliar N. Although NUE generally declines as yields increase, applications of foliar N at the correct time could increase yield and still remain more efficient than the recommended soil applied rate.

Cotton receiving the recommended rate of 134 kg N ha^{-1} showed no signs of N deficiency during the season and resulted in the greatest yield. Increased N apparently had the potential to do two things. One is to provide ample vegetative growth to allow for more branching and production of more fruiting sites. The other is to provide adequate photosynthate to meet the demand of those additional developing bolls. Cotton grown on fine textured soils exhibits growth characteristics unlike those grown on coarser textured type soils. One problem that is often observed in clay soils is the failure of the crop to achieve canopy closure and adequate plant height. Fast fruiting, more determinate varieties grown today tend to partition more into reproductive structures and less into vegetative tissues (Meredeth et al., 1997). Rapid fruiting occurring in the lower portion of the plant canopy may prevent cotton fertilized with minimal soil-applied N from achieving maximum plant height and canopy closure. In an effort to achieve earlier maturity, cotton partitions more resources into reproductive structures rather than vegetative structures and roots. Although earliness is beneficial from the standpoint of avoiding late season insect populations or harvesting difficulties, it provides a smaller window of opportunity for correcting deficiencies. This could be detrimental to a crop grown on a clay soil where vegetative growth is at a premium. Once the plant attains maximum canopy development, individual leaves begin to senesce, which leads to a general decline in canopy photosynthesis. If this decline in canopy photosynthesis coincides with maximum assimilate demand, yield suffers (Wullschelger and Oosterhuis, 1992). Because cotton grown on a clay soil has the potential for decreased vegetative growth and poor canopy development, early N management becomes more important. Oosterhuis et al., 1983 have shown that as sink demand (squares and bolls) increases, N is remoblilized from leaves and redistributed to the developing bolls. N concentrations were highest in leaf blades at 44 DAP in 1999 and 37 DAP in 2000 (Figures 3.1, 3.2). N concentrations decreased sharply as blooming began. This decrease in leaf N is consistent with the findings of Oosterhuis et al., 1983 who found that cotton grown in South Africa remobilized N from leaves as blooming began and demand for photosynthates increased. This remobilization is important, especially in clay soils when root activity declines due to reproduction and poor soil conditions. The increase in leaf N early in the season by plots fertilized with 134 kg N ha^{-1}

and the subsequent remobilization could be the reason for the increased fruit retention and seedcotton weight. It is also possible that some remobilized N is transported to roots that could possibly sustain root activity during times of drought. Because N is associated with fraction one protein involved in photosynthesis, it is of utmost importance that adequate leaf N be available before the onset of blooming. This along with canopy development could play a major role in yield of cotton grown on clay soils. These factors would place a premium on adequate soil N at the beginning of the season and rapid correction if deficiencies did occur. Yield of cotton grown on clay soils appears to be related to achieving adequate plant height and canopy closure and ensuring that plants have adequate N provides a foundation for both.

CHAPTER 4

EFFECT OF PREPLANT N APPLICATION ON EARLY SEASON ROOT AND SHOOT GROWTH AND N ACCUMULATION OF COTTON GROWN ON CLAY SOILS

4.1 Introduction

In a previous field study conducted by the author, cotton fertilized with the recommended rate of 134 kg N ha^{-1} not only had greater seedcotton yields than all other treatments, but appeared to withstand dry soil conditions during boll fill and maintained adequate N concentrations in the youngest fully expanded leaf. Cotton receiving minimal soil N at planting (44 or 67 kg N ha^{-1}) had a similar cosmetic appearance but N concentrations of that leaf and end of season yield were much less than the cotton receiving 134 kg N ha^{-1}.

Root growth of cotton grown on fine textured soils is often impeded due to soil strength, low O_2 concentration (Patrick et al., 1973) and drought stress. Additional problems associated with clay soils include waterlogging that could promote denitrification and reduced uptake, NH_4^+ binding to clay particles and soil cracking that leads to reduced root efficiency. Because of the importance of early season root growth in cotton, many studies have been conducted to evaluate the use of starter fertilizers and plant growth regulators (PGR's) (Kovar and Funderburg, 1992; Hutchinson and Howard, 1997; Stewart and Edmisten, 1998; Howard et al., 1999). Starter fertilizers generally contain N and phosphorus (11-37-0) with the majority being phosphorus (Hutchinson and Howard, 1997; Stewart and Edmisten, 1998; Howard et al., 1999). It is generally thought that preplant rates of N stimulate vegetative growth and phosphorus stimulates root growth. Previous studies have shown that crop response to starter fertilizers varies with year, tillage system soil type, method of application, rate and nutrient concentrations within the starter (Howard et al., 1999). High rates of N at planting has often caused a decrease in the root:shoot ratio. Murata (1969) showed that 90% of photosynthate was partitioned to shoots of rice when grown under high N conditions. However, plants grown under low N conditions tended to partition only 50% of their photosynthate to shoot. It is generally thought that new shoot growth stimulated by increased N acts as a stronger sink for photosynthate than roots under these conditions (Murata, 1969). As a rule, tops are favored when water and N are plentiful but roots are favored when these factors are limited. Zhang et al. (1998) found that grapefruit trees grown under irrigation in poorly drained soils responded with larger fibrous root systems after application of large amounts of NH_4N0_3. Although this information disputes claims that root growth is inhibited by high N rates, it may explain the response of cotton plants to large amounts of fertilizer N applied to cotton grown on low oxygen, poorly drained clay soils. Adequate leaf and shoot N may also be of importance. Maximum demand for N often coincides with periods of reduced root efficiency and declining leaf photosynthesis (Wullschelger and Oosterhuis, 1992). In order to meet the demands of the maturing bolls, plants often re-assimilate N from shoots and older leaves (Oosterhuis et al., 1983). For this reason, adequate assimilation of N before demand reaches maximum is important. The objective of this experiment was to determine early-season indices of growth for roots and shoots and N concentration and distribution for cotton grown on a clay soil under three N regimes.

4.2 Materials and Methods

A study evaluating the effects of preplant N rates on root growth and N distribution of cotton was conducted at the Louisiana State University Ben Hur research farm, Baton Rouge, LA. Sharkey clay soil (very fine, montmorillonitic, non-acid, thermic, Vertic Haplaquepts) was collected from a fallow site near the campus. Soil collected from the site was removed from the top 15 cm and pulverized to achieve a uniform mixture. Selected soil properties are found in table 4.1. Soil was placed into PVC cylinders 30 cm in diameter and 60 cm deep. A wooden bottom was attached to each cylinder to make a closed container. Each cylinder was filled with approximately 168 kg air dried soil. As soil was added, water was added with the soil to bring the soil to field capacity. In order to simulate field growing conditions, cylinders were lowered into large holes so the soil surface of a cylinder was at field level (Figure A3). Cylinders were spaced 1 m apart to avoid any confounding competition among treatments. Sand was used to fill the area around the cylinders to ensure no cylinder movement and allow proper drainage. Cylinders were allowed to sit in the field for one week to allow soil to reach ambient soil temperature and moisture. The experiment consisted of 3 fertilizer treatments replicated four times. Treatments were arranged in a randomized complete block design with each row of cylinders serving as a block to account for any variation that might occur due to location.

Six cotton seeds, cv. STV 474 (Stoneville Pedigreed Seed Company, Memphis, TN), were sown in each cylinder to ensure adequate seedling emergence. After emergence, seedling numbers were thinned to a uniform population of 2 plants cylinder^{-1}. After thinning, NH_4NO_3 was added to cylinders at rates of 0, 44 and 134 kg N ha^{-1}. All plants were grown under field conditions with no supplemental irrigation. Cylinders were weeded weekly and prophylactic applications of pyrethroid insecticide were made at that time to ensure pest problems did not occur.

When plants had initiated fruiting (pin-head square stage, ~30 DAP), each plant was measured for plant height. After plant measurements, the upper most fully expanded leaf of each plant was removed for leaf blade analysis. Plants were cut at the soil surface and the remainder of the leaves was removed and leaf area determined with a LICOR 3000 area meter (LICOR, Lincoln, Nebraska). Leaves and plant stems were oven dried at 65^{o}C for 48 hr. in a forced air dryer and weighed. All samples were then ground using a Wiley Mill (Thomas Scientific Swedesboro, NJ) to pass a 0.5 mm screen. Ground tissue was analyzed using a Leco FP-428 N analyzer (LECO St. Joseph, MI) and total N concentration was determined (total-Kjeldahl- N equivalent)(Bell et al. 1997, 1998).

After plant removal, cylinders were excavated from the field and immediately stored at 1.5^{o}C to prevent root deterioration. A high pressure washing system was used to separate the roots from soil. Roots were collected as the effluent passed through a series of wire mesh sieves. Collected roots were placed into a 50% ethanol solution and refrigerated. After all samples had been collected, debris was removed and cleaned from the roots. Roots were submerged in a shallow pool of 50% ethanol in a clear plexiglass container to encourage separation and scanned using a HP 4400c flatbed scanner (Hewlett Packard, Palo Alto, CA). Total root length was measured from scanned images using the computer software GSROOT (PP Systems Inc., Bradford, MA). After roots were scanned, they were dried at 65^{o} C for 48 hr. and weighed. Shoot:root ratios, root length:leaf area ratios, leaf area ratios (LAR), leaf blade and total N were all calculated. The experiment was repeated twice and because there were no significant differences between duplicate tests, data were pooled. Analysis of variance procedures were conducted using PROC GLM (SAS, 2000) and means were separated using Fisher's protected LSD ($\propto$=0.05).

4.3 Results

Selected soil properties of the Sharkey clay soil used for this study are found in table 4.1.

Table 4.1. Selected soil properties of Sharkey clay used in root study, 2001.

pH	OM	Sum of Bases	P	Na	K	Ca	Mg	AL	Cu	Fe	Mn	Zn
	-%-	meq 100 g^{-1}	---------------------------------mg kg^{-1}------------------------------------									
7.7	2.5	27	230	212	282	3802	821	0.7	3	72	65	3

Nitrogen rate had no effect on plant height. Cotton receiving 44 and 134 kg N ha^{-1} was numerically taller than cotton receiving 0 N but no significant differences occurred. Leaf area followed the same trend as plant height and no differences occurred among N rate treatments, confirming visual observations of cotton in the previous field studies that did not show any growth differences at this stage. Because all plants were similar in size, there were no significant differences in plant dry weight. Plants in this study were harvested shortly after pin-head square. Had plants been harvested at a later date, differences in above-ground biomass might have observed between unfertilized and fertilized treatments.

Root length was not significantly affected by N treatment. Root lengths were highly variable but a numerical trend was suggestive of root length decreased with increasing N (Table 4.2). Root weight followed the same trend as root length, decreasing with addition of N. From the standpoint of partitioning, root length to leaf area ratio was significantly higher in cotton receiving 0 N. Plots receiving 44 or 134 kg N ha^{-1} had statistically similar ratios and were about 30% less than the control (0 N). Plots receiving 0 N had about 0.5 cm of root for each cm^2 of leaf area compared to 0.3 cm cm^{-2} in the fertilized cotton. Root to shoot ratios were also increased as a result of an increase in root weight of cotton receiving 0 N. Root to shoot ratios were about 30% greater in the unfertilized cotton than in the fertilized cotton. Results are consistent with the premise that shoot growth takes precedence over root growth when water and nutrients are readily available. These results indicate that N applications tend to reduce root growth by more dry matter partitioning to the shoot. Therefore, a larger root system would not be a factor in maintaining higher N assimilation for cotton fertilized with the recommended rate of 134 kg N ha^{-1} even under reduced surface moisture conditions at later stages of growth. Thus leaf accumulation of N for remobilization later in the season is an important component

Table 4.2. Plant height, dry weights, root length and allometry of cv. STV 474 at 30 DAP grown on Sharkey clay soil, 2001. Average of two experiments.

Preplant N	Leaf Area	Root Length	Stem	Leaf	Root	Plant Height	Root Length: Leaf Area	Root: Shoot	Leaf Area Ratio
kg ha^{-1}	cm^2	cm	---Dry Weight g---			---cm---	cm cm^{-2}	--g g^{-1}--	cm^2 g^{-1}
0	1595.0	714.6	5.2	7.0	2.8	29.6	0.47	0.6	148.0
44	2106.0	667.2	6.6	9.8	2.6	34.8	0.32	0.4	129.9
134	1980.0	595.5	5.9	9.0	2.4	32.6	0.30	0.4	134.0
LSD (0.05)	NS†	NS	NS	NS	NS	NS	0.13	0.1	NS

†=Non-significant (p≤0.05)

Table 4.3. Nitrogen concentration in UFEL and total N at pin-head square in leaves and stems of cv. STV 474 grown on Sharkey clay soil, 2001. Average of two experiments.

Preplant N	UFEL†	Leaf	Stem	Total
---kg ha^{-1}----	-g N kg^{-1}-	---------------g N plant^{-1}-----------------		
0	37.56	0.223	0.075	0.298
44	49.41	0.423	0.171	0.596
134	52.65	0.428	0.188	0.618
LSD (0.05)	6.2	0.143	0.051	0.194

†UFEL=Uppermost fully expanded leaf.
‡=Non-significant (p≤0.05).

Nitrogen in the uppermost fully expanded leaf (UFEL) of cotton in this study had similar values as cotton grown in the field. Nitrogen concentrations in the UFEL of 44 and 134 kg N ha^{-1} treatments were significantly higher than cotton in the unfertilized control (Table 4.3). Nitrogen accumulation in leaves and stems followed the same trend as the UFEL. Applied N significantly increased total N in leaves and shoot but differences between N rates were non-significant. Root N was unaffected by N rate but results are probably invalid due to NO_3^- leaching from roots in ethanol solution.

4.4 Discussion

Preplant N rate appeared to have no significant effect on the root length or mass of cotton roots per se but did affect relative partitioning in favor of shoot growth. The hypothesis that N application at planting stimulated early season root growth and resulted in increased yield was not valid. One possible reason for the increase in yield was that the increased N provided ample vegetative growth to allow for more branching and production of more fruiting sites. The production of fruiting sites is closely related with vegetative growth since it is responsible for the production of both new sympodia and additional nodes on existing sympodia (Mauney, 1979; Wells and Meredeth, 1984). This was not seen in this study because plants were similar in size due to the time of sampling. Sampling at a later date may have shown differences in leaf area and plant height but was not possible in this study due to the cylinder size that would have confounded root results. The other is to provide adequate assimilate to meet the demand of those additional developing bolls. Oosterhuis et al. 1983 have shown that as sink demand increases, N is remoblilized from leaves and redistributed to the developing bolls. This redistribution of stored N is important when the bolls become the primary sink for assimilates (Rosolem and Mikkelsen, 1989). The author has observed that N concentrations were highest in leaf blades at 44 DAP in 1999 and 37 DAP in 2000 in field studies (Figures 3.1, 3.2) and N concentrations decreased sharply as blooming began. This decrease in leaf N is consistent with the findings of Oosterhuis et al. 1983 who found that cotton grown in South Africa remobilized N from leaves as blooming began and demand for photosynthates increased. At 37 DAP, leaf N concentrations (UFEL) were significantly higher in fertilized cotton and similar to those reported in the previous field study (Chapter 3). This increase in N early in the season is important, especially in clay soils when root activity declines due to reproductive sink strength and poor soil conditions as occurred in the field study. Assuming a continual increase in leaf N early in the season by plots fertilized with 134 kg N ha^{-1}, subsequent remobilization could be the reason for the increased fruit retention and seedcotton weight. It is also possible that some remobilized N is transported to roots that could possibly sustain root activity during times of drought. From this study and previous field studies it is evident that increased leaf N early in the season is important so that adequate leaf N is available during boll fill. This along with canopy photosynthesis could play a major role in yield of cotton grown on clay soils. These factors would place a premium on adequate soil N at the beginning of the season and rapid correction if deficiencies did occur. Yield of cotton grown on clay soils appears to be related to achieving adequate plant height and canopy closure and insuring that plants have adequate N provides a foundation for both.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

The residual effects of N remaining after application of high rates of N were apparent in cotton yields in the year following rotation with corn. Applications of large amounts of cotton-applied N (112 kg ha^{-1}) were not necessary to maintain optimum yield of cotton, when following corn N rates of 280 kg N ha^{-1}. When N availability to cotton increased, yield was shifted to the upper third of the plant. This temporal shift in yield could have been detrimental if unfavorable conditions existed late in the growing season. Total dry matter production and N assimilation increased as previous and applied N rates increased. Recovery of ^{15}N was greatest in cotton following 0 or 168 kg corn-applied N ha^{-1}, decreasing significantly following 280 kg corn-applied N ha^{-1}. Recovery of labeled N ranged from 40-53% in 1999 and from 30-58% in 2000. Application of 112 kg cotton-applied N ha^{-1} to cotton increased total ^{15}N assimilated compared to the 56 kg cotton-applied N ha^{-1} rate but apparent efficiency was decreased with this N rate when following 168 or 280 kg corn-applied N ha^{-1}. The decrease in apparent efficiency was presumed to be due to the dilution of applied N since the amount of N derived from soil (Ndfs) increased as corn-applied N increased. This dilution of ^{15}N resulted a decrease in apparent uptake efficiency. Regardless of the mechanism causing the decreased recovery and reduced uptake efficiency, the fact remains that applications of large amounts of N are not fully utilized nor required for optimum dry matter production and yield of cotton. As this uptake efficiency decreases, benefits (both agronomically and economically) of increased rate of N are no longer realized.

Maximizing seedcotton yield was not successful using less than optimall soil-applied N along with triggered foliar applications of N as needed (FAN). Cotton receiving the recommended soil-applied rate of 134 kg N ha^{-1} showed no signs of N deficiency during the season and resulted in the greatest yield while cotton receiving minimal soil-applied N required several foliar applications and did not produce yields comparable to the recommended practice. Differences in yield between the cotton receiving the recommended rates of N and the minimal soil-applied N + FAN were due to increased boll number and ultimately seedcotton found on the upper sympodial branches and outer fruiting positions. The adequately fertilized cotton was able to support these additional bolls during periods of drought and reduced root efficiency presumably due to re-distribution of stored N. Increased N apparently provided ample vegetative growth that allowed for increased sympodial branching and production of more fruiting sites and also provided adequate assimilate to meet the demand of those additional developing bolls. Although seedcotton yield was 20% less than optimal yields for treatments receiving FAN, the N use efficiency (NUE) was 33% greater than the recommended soil-applied treatment of 134 kg N ha^{-1}. Reevaluation of critical values suggested that leaf N critical values of 40 g N kg^{-1} prior to early bloom was too low and that increasing leaf N critical values to 43 g N kg^{-1} would have triggered applications of N sooner and possibly maintained leaf N concentrations above critical levels during boll fill.

Preplant N application adjusted root/shoot partitioning in favor of shoot growth. Shoots accumulated more N with preplant N treatments. Although no significant difference was found between 44 and 134 kg preplant N ha^{-1} at the pin-head square, the 134 kg N ha^{-1} treatment had a higher average N concentration and may have increased N accumulation in later growth stages.

5.2 Conclusions

The rotation of cotton and corn in the Midsouth will continue as long as prices and yield benefits are realized. The contribution of residual N will vary from year to year and location to location. Data from this study indicate that large amounts of fertilizer are not necessary for optimum yield and could be detrimental in some years. The reduced uptake efficiency at higher N rates results in an increase in fertilizer N remaining in the soil after harvest that could result in environmental pollution. Optimum yields of cotton can be made with minimal soil applied N when following higher rates of previous corn-applied N.

If N use is regulated and the current amount of N required for optimal yield on clay soils is no longer within the regulated guidelines, foliar applications of N (FAN) will offer an option to provide the necessary N. When coupled with minimal soil-applied N, the timing of these applications of foliar N are critical and must be applied early in the growing season to avoid periods of N stress. Triggering applications earlier due to improved critical N thresholds may result in maintaining leaf N concentrations above critical levels as sink demand increases. Since it was shown that FAN treatments resulted in greater NUE and yield was only 20% below optimum, increasing critical values along with properly timed FAN may result in optimum yields with greater NUE.

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APPENDIX: TABLES AND FIGURES

Table A.1. Selected soil properties of Commerce silt loam cropped to cotton and corn in rotation, 1999-2000.

N Rate									
Corn	Cotton	pH	P	Na	K	Ca	Mg	OM	Sum of Bases
----kg N ha^{-1}----			----------------mg kg^{-1}----------------					%	Meq 100 g^{-1}
0	0	6.7	204.8	9.0	102.0	1093.9	166.9	0.6	7.1
0	56	6.4	212.9	11.1	96.5	1087.0	166.1	0.7	7.1
0	112	6.5	217.1	13.8	104.4	1153.9	172.1	0.7	7.5
168	0	6.6	207.6	8.2	100.0	1069.3	158.0	0.7	6.9
168	56	6.4	205.3	9.7	93.9	1040.8	156.6	0.6	6.8
168	112	6.2	213.8	9.4	102.3	1046.9	153.1	0.8	6.8
280	0	6.1	198.7	8.9	98.4	999.1	156.2	0.7	6.6
280	56	5.9	214.3	9.9	96.6	1019.2	159.7	0.7	6.7
280	112	6.0	211.0	10.7	93.9	1007.7	148.1	0.7	6.5

Table A.2. Effect of residual and applied N on the total N in the soil profile of Commerce silt loam cropped to cotton and corn in rotation, 1999-2000.

N Rate		Sampling Depth (cm)							
Corn	Cotton	0-15	16-30	31-45	46-60	60-75	76-90	91-105	106-120
-kg ha-1-		ppm N							
0	0	583	380	377	357	287	277	220	236
0	0	640	477	523	503	530	530	480	547
168	0	467	323	417	350	247	290	310	237
168	0	725	530	505	503	428	423	375	405
280	0	587	333	347	247	310	320	303	297
280	0	640	530	433	477	460	443	340	383
0	56	990	790	600	347	290	267	233	270
0	56	620	437	470	427	327	430	340	283
168	56	543	460	457	460	540	507	300	300
168	56	625	475	525	535	445	495	435	330
280	56	867	483	477	470	423	347	327	323
280	56	667	623	433	463	430	447	460	487
0	112	590	543	510	467	413	423	350	383
0	112	540	430	413	320	317	313	353	437
168	112	653	453	480	450	443	433	433	387
168	112	620	460	360	303	890	283	227	257
280	112	670	477	433	460	490	393	393	447
280	112	510	377	290	303	377	290	200	240

Table A.3. Atom% ^{15}N values of the surface 30 cm of soil after crop removal, 1999-2000.

Year	N Rate		Mass Spectrometer Values	
	Corn	Cotton	ATM%	ATM% Excess
	-----kg ha^{-1}-----			
1999	0	56	0.376	0.005
2000	0	56	0.516	0.146
1999	168	56	0.389	0.018
2000	168	56	0.491	0.121
1999	280	56	0.383	0.013
2000	280	56	0.615	0.244
1999	0	112	0.431	0.061
2000	0	112	0.552	0.181
1999	168	112	0.424	0.054
2000	168	112	0.611	0.241
1999	280	112	0.415	0.044
2000	280	112	0.679	0.309

Table A.4. Effect of residual and applied N on the node above white flower values of cotton grown in rotation with corn, 19999-2000.

Year	N Rate		Days After Planting				
	Cotton	Corn					
	---kg ha^{-1}---				NAWF		
1999	0	0	7.0	6.6	3.8	-------	-------
2000	0	0	5.6	-------	-------	2.7	1.8
1999	168	0	6.8	6.6	4.1	-------	-------
2000	168	0	5.5	-------	-------	3.5	2.5
1999	280	0	7.4	7.0	4.7	-------	-------
2000	280	0	5.8	-------	-------	3.9	2.7
1999	0	56	7.4	7.2	4.3	-------	-------
2000	0	56	5.9	-------	-------	3.1	3.4
1999	168	56	7.1	6.9	4.4	-------	-------
2000	168	56	6.3	-------	-------	3.6	2.6
1999	280	56	7.3	7.1	4.6	-------	-------
2000	280	56	6.3	-------	-------	4.2	3.2
1999	0	112	7.4	7.2	4.9	-------	-------
2000	0	112	6.2	-------	-------	3.8	2.9
1999	168	112	7.2	7.3	4.9	-------	-------
2000	168	112	5.5	-------	-------	4.1	2.8
1999	280	112	7.5	7.1	5.1	-------	-------
2000	280	112	5.8	-------	-------	3.3	2.9

Table A.5. Effect of residual and applied N on the height to node ratio of cotton grown in rotation with corn, 1999-2000.

Year	N Rate		Days After Planting				
	Cotton	Corn	51	58	65	72	79
	---kg ha^{-1}---		Height:Node Ratio				
1999	0	0	-------	2.30	2.37	2.47	2.90
2000	0	0	2.70	2.90	2.75	-------	-------
1999	168	0	-------	2.43	2.57	2.57	2.73
2000	168	0	2.80	2.90	2.95	-------	-------
1999	280	0	-------	2.57	2.77	2.73	3.23
2000	280	0	2.97	3.07	3.50	-------	-------
1999	0	56	-------	2.60	2.80	2.73	3.20
2000	0	56	2.93	3.33	3.23	-------	-------
1999	168	56	-------	2.40	2.70	2.70	3.10
2000	168	56	2.93	2.93	3.00	-------	-------
1999	280	56	-------	2.53	2.97	2.80	3.03
2000	280	56	2.93	2.70	3.13	-------	-------
1999	0	112	-------	2.50	2.67	2.73	3.30
2000	0	112	2.70	3.45	3.20	-------	-------
1999	168	112	-------	2.53	2.67	2.77	3.27
2000	168	112	3.10	2.80	2.60	-------	-------
1999	280	112	-------	2.47	2.87	2.80	2.97
2000	280	112	2.80	2.83	3.13	-------	-------

Table A.6. Effect of residual and applied N on leaf chlorophyll of cotton grown in rotation with corn as determined by a hand held chlorophyll meter, 1999-2000.

	N Rate		Days After Planting								
Year	Cotton	Corn	37	44	51	58	65	72	79	86	93
						SPAD Reading					
1999	0	0	37.9	35.5	34.9	35.2	29.8	30.7	31.7	29.7	31.0
2000	0	0	-------	-------	-------	40.0	28.9	18.1	31.6	34.7	-------
1999	168	0	37.9	34.8	35.5	37.8	29.9	30.9	32.7	32.7	33.7
2000	168	0	-------	-------	-------	34.6	29.9	32.5	34.9	37.1	-------
1999	280	0	41.1	37.9	37.7	38.3	32.9	36.0	38.0	38.7	40.0
2000	280	0	-------	-------	-------	35.6	31.3	34.6	34.5	40.9	-------
1999	0	56	43.0	37.8	36.5	36.7	32.0	35.1	35.3	36.0	37.7
2000	0	56	-------	-------	-------	36.5	30.9	32.1	33.0	38.5	-------
1999	168	56	42.4	38.7	37.8	37.6	32.3	35.8	37.6	36.9	38.9
2000	168	56	-------	-------	-------	37.6	31.8	33.7	36.2	39.9	-------
1999	280	56	42.7	39.7	38.8	38.3	34.0	38.6	40.0	41.7	45.8
2000	280	56	-------	-------	-------	38.7	33.6	36.3	33.0	40.2	-------
1999	0	112	42.9	38.2	36.8	37.0	32.4	38.2	40.5	42.0	41.9
2000	0	112	-------	-------	-------	40.1	33.5	33.7	34.7	39.1	-------
1999	168	112	44.3	39.8	38.4	37.1	32.9	36.7	39.7	43.5	43.6
2000	168	112	-------	-------	-------	38.6	31.7	37.1	35.1	44.3	-------
1999	280	112	43.9	40.3	40.4	37.2	34.2	40.1	41.0	44.7	45.3
2000	280	112	-------	-------	-------	39.3	32.5	36.9	38.7	41.6	-------

Table A.7. Effect of N treatment on the height:node ratio of cotton cv. STV 474 grown on Sharkey clay, 1999-2000.

		Days After Planting				
Year	N Rate					
	-kg ha^{-1}-	-------------------Height:Node Ratio cm node^{-1}-------------				
1999	0/0/0	1.7	1.7	1.9	2.2	-------
2000	0/0/0	-------	2.4	1.7	1.7	1.8
1999	0/0/AN	1.6	1.8	2.0	2.3	-------
2000	0/0/AN	-------	2.4	1.7	1.7	1.8
1999	44/0/0	-------	-------	-------	-------	-------
2000	44/0/0		2.2	1.8	1.9	1.9
1999	44/0/AN	1.7	1.8	2.0	2.4	-------
2000	44/0/AN	-------	2.3	1.8	1.8	2.0
1999	67/0/0	-------	-------	-------	-------	-------
2000	67/0/0	-------	2.2	1.8	1.9	2.0
1999	67/0/FAN	-------	-------	-------	-------	-------
2000	67/0/FAN	-------	2.3	1.8	1.9	2.0
1999	67/0/44	-------	-------	-------	-------	-------
2000	67/0/44	-------	2.4	1.8	1.8	2.0
1999	67/67/0	-------	2.3	1.7	1.8	2.0
2000	67/67/0	-------	-------	-------	-------	-------
1999	44/90/0	1.5	1.8	2.0	2.4	-------
2000	44/90/0	-------	-------	-------	-------	-------
1999	134/0/0	1.5	1.65	2.1	2.5	-------
2000	134/0/0	-------	2.2	1.9	1.9	2.0

Table A.8. Effect of N treatment on the chlorophyll content of leaves of cotton cv. STV 474 grown on Sharkey clay, 1999-2000.

		Days After Planting							
Year	N Rate	30	37	44	51	58	65	72	79
	-kg ha^{-1}-	SPAD Reading							
1999	0/0/0	-------	40.0	37.0	33.6	26.3	30.0	33.6	34.2
2000	0/0/0	35.2	33.4	35.2	33.8	31.9	29.6	31.4	-------
1999	0/0/AN	-------	39.6	36.4	33.0	27.3	31.8	34.0	36.3
2000	0/0/AN	34.6	35.9	35.6	36.9	35.6	31.5	34.5	33.9
1999	44/0/0	-------	-------	-------	-------	-------	-------	----------	-------
2000	44/0/0	38.4	35.5	38.4	37.1	35.8	30.2	33.2	34.2
1999	44/0/AN	-------	40.3	36.6	33.6	29.7	33.2	37.2	38.4
2000	44/0/AN	36.4	37.1	38.2	39.1	35.8	31.4	34.2	34.4
1999	67/0/0	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/0	38.4	36.3	38.9	38.4	35.7	31.5	36.1	36.1
1999	67/0/FAN	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/FAN	39.3	37.1	39.0	39.2	36.3	31.4	36.0	36.4
1999	67/0/44	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/44	37.9	37.1	39.1	38.9	35.8	32.2	36.5	34.8
1999	67/67/0	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/67/0	38.2	37.1	39.0	39.33	35.7	31.7	39.3	39.0
1999	44/90/0	-------	40.7	36.1	33.2	28.5	35.8	39.2	40.3
2000	44/90/0	37.7	37.8	39.8	40.1	36.1	31.6	38.6	38.0
1999	134/0/0	-------	40.2	36.7	32.5	30.4	34.7	39.9	40.9
2000	134/0/0	39.2	37.4	39.6	40.6	35.6	31.8	38.2	36.4

Table A.9. Effect of N treatment on leaf blade N concentrations of cotton cv. SG 125 grown on Commerce silt loam, 1999-2000.

Year	N Rate	Days After Planting									
		30	37	44	51	58	65	72	79	86	93
		---------------g N kg^{-1}---------------									
1999	0/0/0	49.3	49.7	30.9	44.7	42.4	37.8	31.4	33.8	25.6	22.1
2000	0/0/0	55.6	53.9	43.2	41.7	41.8	40.6	42.8	41.5	-------	-------
1999	0/0/AN	51.2	48.7	30.5	44.3	42.6	37.2	34.2	34.8	30.1	27.9
2000	0/0/AN	58.2	51.9	39.1	38.7	42.0	39.8	43.3	36.9	-------	-------
1999	34/0/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/0	56.3	54.2	45.9	45.3	43.1	42.6	41.9	42.3	-------	-------
1999	34/0/FAN	51.0	49.2	30.0	46.0	50.3	47.1	36.9	41.0	28.3	28.4
2000	34/0/FAN	56.8	55.8	45.1	45.4	46.6	44.0	44.8	41.7	-------	-------
1999	34/0/56	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/56	55.8	56.5	45.0	44.1	45.2	42.7	47.0	40.0	-------	-------
1999	34/56§/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/56/0	57.0	58.3	43.6	44.2	45.4	40.9	46.3	40.4	-------	-------
1999	56/0/34	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	56/0/34	58.8	55.5	42.6	48.7	48.5	44.0	48.0	40.2	-------	-------
1999	67/0/22	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/22	57.8	56.6	47.0	47.3	46.7	45.7	46.0	40.5	-------	-------
1999	34/56/0	48.1	50.7	32.0	47.9	54.5	52.9	41.9	45.9	35.5	32.3
2000	34/56/0	55.1	58.4	44.8	43.6	42.1	41.5	43.6	47.4	-------	-------
1999	90/0/0	49.6	52.0	31.1	47.7	53.9	52.8	41.0	45.6	34.7	31.4
2000	90/0/0	58.8	57.0	46.1	45.5	45.0	43.5	43.1	44.8	-------	-------

Table A.10. Effect of N treatment on the height:node ratio of cotton cv. SG 125 grown on Commerce silt loam, 1999-2000.

		Days After Planting			
Year	N Rate	51	65	79	93
	-kg ha^{-1}-	-------------------Height:Node Ratio cm node^{-1}-------------			
1999	0/0/0	2.2	2.5	2.4	2.8
2000	0/0/0	2.0	2.5	2.6	2.6
1999	0/0/AN	2.2	2.5	2.4	2.9
2000	0/0/AN	1.8	2.7	2.9	2.9
1999	34/0/0	-------	-------	-------	-------
2000	34/0/0	1.9	2.6	2.5	2.5
1999	34/0/FAN	2.2	2.4	2.5	3.0
2000	34/0/FAN	1.9	2.5	2.7	2.9
1999	34/0/56	-------	-------	-------	-------
2000	34/0/56	2.0	2.8	2.7	2.4
1999	34/56§/0	-------	-------	-------	-------
2000	34/56/0	1.7	2.8	2.7	2.7
1999	56/0/34	-------	-------	-------	-------
2000	56/0/34	1.9	2.6	2.8	2.7
1999	67/0/22	-------	-------	-------	-------
2000	67/0/22	1.8	2.3	2.8	2.5
1999	34/56/0	2.2	2.5	2.5	3.1
2000	34/56/0	2.0	2.7	2.7	2.7
1999	90/0/0	2.3	2.6	2.6	3.0
2000	90/0/0	1.9	2.4	2.8	2.7

Table A.11. Effect of N treatment on the chlorophyll content of leaves of cotton cv. SG 125 grown on Commerce silt loam, 1999-2000.

		Days After Planting									
Year	N Rate	30	37	44	51	58	65	72	79	86	93
	-kg ha^{-1}-	SPAD Reading									
1999	0/0/0	-------	44.3	44.5	39.3	35.8	30.2	34.1	36.0	36.3	35.8
2000	0/0/0	39.0	39.4	37.2	35.5	38.3	38.8	42.0	-------	-------	-------
1999	0/0/AN	-------	44.2	41.7	39.4	35.9	30.6	33.4	37.2	39.0	38.3
2000	0/0/AN	37.8	39.2	35.1	35.0	39.2	40.2	41.9	-------	-------	-------
1999	34/0/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/0	39.0	40.9	38.8	38.8	41.5	41.1	44.4	-------	-------	-------
1999	34/0/AN	-------	45.4	42.9	39.8	36.8	31.8	37.2	38.8	40.5	40.5
2000	34/0/AN	39.7	39.8	38.4	38.0	40.7	40.7	44.6	-------	-------	-------
1999	34/0/56	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/56	39.0	39.9	39.4	37.9	40.0	42.7	44.4	-------	-------	-------
1999	34/56/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/56/0	39.1	38.4	37.3	37.2	40.4	41.4	44.8	-------	-------	-------
1999	56/0/34	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	56/0/34	38.0	40.2	39.0	39.4	41.5	41.2	45.3	-------	-------	-------
1999	67/0/22	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/22	38.7	40.4	38.5	36.9	41.7	42.7	45.0	-------	-------	-------
1999	34/56/0	-------	45.3	42.4	40.4	36.9	31.4	38.7	40.8	42.6	45.4
2000	34/56/0	38.5	40.5	37.5	35.6	38.9	39.9	44.9	-------	-------	-------
1999	90/0/0	-------	46.2	42.7	39.1	35.7	31.4	37.9	41.2	43.0	44.1
2000	90/0/0	40.0	40.0	38.2	38.6	42.1	42.7	44.6	-------	-------	-------

Table A.12. Effect of N treatment on seedcotton yield of cv. SG 125 grown on Commerce silt loam, 1999-2000.

Preplant N	Sidedress N	Foliar N	Seedcotton		
			1999	2000	2 Year Avg.
---kg ha $^{-1}$---					
0	0	0	2666	2075	2370.5
0	0	FAN	3055	2478	2766.5
34	0	0	-------	2006	-------
34	0	FAN	3234	2127	2680.5
34	0	56	-------	2020	-------
56	0	34	-------	2070	-------
67	0	22	-------	1583	-------
34	56 SAN	0	-------	2227	-------
34	56	0	3582	2292	2937
90	0	0	3548	2084	2816

Table A.13. Temporal and spatial effect of N treatment on partitioning of seedcotton yield of cv. SG 125 grown on Commerce silt loam determined by boxmapping procedures, 1999-2000.

Year	N Rate		Horizon 1			Horizon 2			Horizon 3			
		Veg	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
	-kg ha^{-1}-	-----------------------------------g m^{-2}--------------------------------------										
1999	0/0/0	17.8	84.2	17.2	8.3	99.2	15.0	0.8	23.3	0.0	0.0	265.8
2000	0/0/0	14.4	114.9	24.8	2.0	57.3	9.5	0.0	6.9	0.0	0.0	229.8
1999	0/0/AN	14.9	96.4	24.3	1.1	118.3	15.1	6.2	36.8	0.7	0.0	313.9
2000	0/0/AN	21.0	121.1	31.5	3.7	73.5	15.2	0.4	9.8	0.0	0.0	276.2
1999	34/0/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/0	15.9	106.6	24.4	2.2	70.2	8.4	0.4	7.6	0.0	0.0	235.7
1999	34/0/AN	12.8	91.7	25.0	9.3	129.5	24.2	4.8	43.3	0.3	0.0	340.9
2000	34/0/AN	27.3	87.2	23.7	5.5	55.1	14.9	0.9	10.2	1.5	0.7	226.9
1999	34/0/56	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/56	23.4	89.1	24.0	2.4	66.7	4.8	0.0	13.6	0.0	0.0	223.9
1999	34/56/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/56/0	23.9	109.8	34.7	5.5	76.3	8.9	0.6	11.1	0.5	0.0	271.3
1999	56/0/34	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	56/0/34	27.9	98.0	21.7	1.3	54.6	7.0	0.0	3.1	0.0	0.0	213.5
1999	67/0/22	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/22	19.4	110.8	24.2	1.3	63.7	7.7	0.6	3.2	0.0	0.0	230.9
1999	34/56/0	16.1	74.2	36.4	8.3	126.3	34.2	9.5	60.9	5.6	0.0	371.6
2000	34/56/0	18.0	129.0	45.1	2.7	86.4	12.4	0.4	11.4	0.0	0.0	305.3
1999	90/0/0	13.3	62.5	27.7	3.5	114.4	31.5	7.0	79.3	11.2	0.7	351.0
2000	90/0/0	18.9	92.0	16.5	5.2	56.6	9.8	0.3	5.1	1.0	0.0	205.3

Table A.14. Temporal and spatial effect of N treatment on boll number of cv. SG 125 grown on Commerce silt loam determined by boxmapping procedures, 1999-2000.

Year	N Rate		Horizon 1			Horizon 2			Horizon 3		
		Veg	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Pos 1	Pos 2	Pos 3	Total
	kg ha^{-1}	-------------------------------------g m^{-2}-------------------------------------										
1999	0/0/0	5.2	20.2	4.5	2.2	24.5	4.5	0.2	7.0	0.0	0.0	68.5
2000	0/0/0	4.5	27.9	6.9	0.8	16.1	2.9	0.0	1.9	0.0	0.0	60.9
1999	0/0/AN	4.5	21.3	6.2	0.2	26.5	4.5	1.8	10.5	0.2	0.0	75.8
2000	0/0/AN	5.9	28.3	7.9	1.3	18.9	4.6	0.1	2.9	0.0	0.0	69.8
1999	34/0/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/0	4.3	27.2	7.6	0.6	18.3	2.9	0.1	2.9	0.0	0.0	63.9
1999	34/0/AN	2.8	20.0	6.5	2.3	29.0	6.0	1.2	11.8	0.2	0.0	79.8
2000	34/0/AN	8.1	21.0	6.5	1.5	14.4	4.1	0.2	3.4	0.6	0.4	60.3
1999	34/0/56	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	34/0/56	6.4	21.8	6.0	0.8	18.3	1.4	0.0	3.1	0.0	0.0	57.6
1999	35/56/0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	35/56/0	7.8	24.6	9.1	1.6	19.1	3.1	0.3	3.1	0.2	0.0	69.0
1999	56/0/34	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	56/0/34	7.4	23.9	6.1	0.4	14.6	1.4	0.0	1.0	0.0	0.0	54.8
1999	67/0/22	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
2000	67/0/22	7.0	25.9	6.5	0.4	16.9	2.6	0.1	0.9	0.0	0.0	60.3
1999	34/56/0	3.3	17.8	8.8	2.0	26.0	8.8	2.5	15.2	1.5	0.0	85.8
2000	34/56/0	5.5	30.3	12.4	0.8	23.1	4.3	0.1	3.4	0.0	0.0	79.8
1999	90/0/0	3.0	14.7	7.0	1.0	24.7	7.5	1.7	19.5	3.3	0.2	82.8
2000	90/0/0	5.5	22.5	4.5	1.9	15.5	2.9	0.1	1.5	0.4	0.0	54.8

Table A.15. Nematode population infesting cotton cv. SG 125 grown on Commerce silt loam, 2000.

Year	N Rate	Reniform	Spiral	Root Knot	Yield
	kg ha^{-1}		Nematode 0.5 L^{-1}		-kg ha^{-1}-
2000	0/0/0	22210	0	0	2075
2000	0/0/FAN	17720	110	0	2478
2000	34/0/0	43640	0	0	2006
2000	34/0/FAN	24835	90	0	2127
2000	34/0/56	20743	10	0	2020
2000	34/56§/0	44320	80	0	2227
2000	56/0/34	32070	0	0	2070
2000	67/0/22	56445	10	20	1583
2000	34/56/0	37760	0	0	2292
2000	90/0/0	27225	10	0	2084

Figure A1. Microplot used to determine the effect of residual and applied N on use efficiency of cotton following corn in rotation, 1999-2000.

Figure A2. Re-pipette syringe used to simulate N sidedressing application of ^{15}N labeled $NH_4NO_3^-$ to cotton following corn in rotation, 1999-2000.

Figure A3. Growth cylinders used to determine the effect of preplant N on root growth of cotton grown on Sharkey clay, 2001.

Figure A4. Soil core and high pressure washing system used to separate soil and roots of cotton grown on Sharkey clay, 2001.

Figure A5. Bitmap image of cotton roots grown on Sharkey clay used to determine root length using GSROOT software.

VITA

Charles Chism Craig, Jr. was born August 28, 1973, in Clarksdale, Mississippi. He was born and raised in the small agricultural community of Friars Point, Mississippi. He graduated from Lee Academy in the spring of 1991 and enrolled at Mississippi State University. He received his undergraduate degree in Agricultural Pest Management in December 1995. He then began work on a Master of Science degree in entomology at Mississippi State in January 1996 and received his degree in August 1998. He enrolled at Louisiana State University in August 1998 to pursue a doctorate in agronomy. He is married to the former Memory Lynn Cox of Greenville, Mississippi and they are expecting their first child.